A TEXT-BOOK OF GEOLOGY

INTENDED AS AN INTRODUCTION TO THE STUDY OF THE ROCKS AND THEIR CONTENTS

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LONDON
BLACKIE & SON, LIMITED, 50 OLD BAILEY, E.C.
GLASGOW AND DUBLIN
1897

PREFACE TO THE NEW EDITION.

This is nominally the fourth edition of a work which first appeared in 1889. But so many additions and alterations have been made that it is practically a new book.

The changes were so extensive as to necessitate the re-setting in new type of the entire work; and the publishers have taken advantage of this to introduce both larger and clearer type and a larger page. Many new illustrations have also been added, several of these being from photographs taken by myself especially for this book.

In Geology, as in all the other sciences, constant and rapid progress is being made. The changes in, and additions to our knowledge of the rocks have been especially great in the strata which form the beginning and the end of the geological series respectively—the Pre-Cambrian and Cambrian Formations at the beginning, and the Glacial Series near the end. Special care has been devoted to bringing these portions of the book up to date.

It has been remarked that "geology cannot be learnt from books"; but it is equally true that geology "cannot be learnt *without* books". Certainly the rocks themselves are the best teachers, but it has taken thousands of years to acquire the power of interpreting the signs of those rocks, and the student must make himself master of the principal facts that the numerous workers in this field of knowledge have already collected. I would urge the student to go direct to nature;

to study, measure, and draw every section—hill-side or quarry, railway cutting and gravel-pit—that may be in his district, and to collect specimens of rocks and fossils from each. He should also attend any geological class to which he can gain admission, and read not only this little text-book, but every book or article upon Geology which he can buy or borrow.

Free libraries, museums, and science classes are rapidly increasing in number, and the student will derive much benefit from each. A collection of specimens of rocks, minerals, and fossils, such as is supplied by several dealers at a moderate cost, will also be useful to him.

Above all things the student of Geology must have *perseverance.* The ideas and terms of the science may at first seem strange, but by use they will become "familiar as household words".

W. JEROME HARRISON.

BIRMINGHAM, *April*, 1897.

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CHAPTER I.

Definition, Object, and History of the Science of Geology.

Definition of Geology.—Geology—the word is derived from the Greek *ge*, the earth, and *logos*, a discourse about, or study of—is the science which investigates the history of the earth. It takes a place between Astronomy and Physical Geography. If we accept the nebular hypothesis, there was a time when the matter which now forms the solar system was in the state of a vast cloud of gaseous or meteoric matter floating in space. This enormous mass of matter slowly cooled and consolidated, and a portion of it now forms the world we live on.[1] The history of this old nebula, and the tale of how it produced the various members of our solar system, belong to the science of Astronomy. Geology may be said to commence with the time when the earth became so far solid as to admit of the formation of what we should call 'rocks' upon the surface. These original or first-formed rocks would resemble the volcanic rocks of the present day, but it is not likely that any trace of them is now left.

Physical Geography studies the surface of the earth *as it*

[1] We can see in the sky at the present day—either with the naked eye or through the telescope—many similar masses of glowing cloudy-looking matter, and to these the name of *Nebulæ* is applied (see fig. 1).

exists at the present day. But the study of this science cannot be separated from that of Geology. To explain what has

Fig. 1.—The Great Nebula in Andromeda—from a photograph by Dr. Isaac Roberts, F.R.S.

happened in the past, we must study the natural changes which are taking place to-day. For we believe that the same forces have acted in the past as in the present, and that we

can only explain the phenomena presented by and in the rocks by the study of the forces of nature as they are seen in action to-day and before our own eyes.

Thus, other things being equal, the keenest observer will make the best geologist. Sharp eyes and strong legs are important items in the outfit of the student of the rocks. As he strays over the beach, the action of the waves upon the sandy shore will enable him to explain the "ripple-mark" which we find in even the most ancient sandstones; while the dead shells buried in the mud will lead him to the understanding of what was so great a puzzle to our ancestors only a century or two ago—viz. "how the fossils got into the rocks?"

The Objects of Geology.—Among the objects of geology we may broadly distinguish those which are strictly scientific, from those which are commercial or economical. Yet it is almost impossible to follow up one of these lines without benefiting the other. Viewed from a commercial point of view, geology is a science of great importance. It teaches us how to recognize the various minerals and ores, and tells us where we may mine for these with a good prospect of success; it shows, too, where underground supplies of water exist which may be utilized for the service of great towns.

The student of geology who has a strictly scientific end in view, endeavours in the first place to discover the mode of origin of the rocks which compose the district he is investigating—whether they have been melted or hardened by heat, or simply deposited in water. Then he tries to find out the order of succession of these rocks—which are the oldest and which the newest. He examines the rocks chemically, and also with the microscope, in order to determine the materials of which they are composed, and the minerals which they contain.

This close examination soon leads the student to discover that many rocks contain the hard parts of animals and plants—fossils—which lived during former periods of the earth's history, and he endeavours to compare these with the existing fauna and flora of to-day.

Divisions of Geology.—For the purposes of this book we shall consider the Science of Geology as divided into three parts.

In Part I.—DESCRIPTIVE GEOLOGY—we give the results which have been obtained by a scientific study of the crust of the earth, such as may now be made. This part has much in common with Physical Geography (or Physiography as it is also termed), especially as connected with the study of those natural forces which are now—as they have been from the beginning—acting upon and modifying the crust of the earth. Included in this part of the subject we also have *Mineralogy*—the study of minerals; and *Petrology*—the study of rocks.

In Part II.—PALÆONTOLOGY—we apply our knowledge of living animals and plants (derived from the sciences of Zoology and Botany) to the study of the *fossils* which are found in rocks. These fossils are the remains of beings—animals and plants—which inhabited our earth in bygone times.

And finally in Part III.—HISTORICAL OR STRATIGRAPHICAL GEOLOGY—we study the stratified rocks in succession, from the oldest to the newest, endeavouring to ascertain from them as much as possible about the past history of the earth.

History of Geology.—The science of Geology had its origin in the observations of miners in such countries as Germany and England, which are rich in minerals and in ores. German books published during the sixteenth and the seventeenth centuries show that in Saxony and elsewhere *an order of succession* of the rocks had even then been ascertained to exist. During the latter part of the eighteenth century, a German professor named Werner described the Brocken Mountains as "a central cone of granite, upon which on all sides round were laid various other rocks in a certain and constant order of succession, as granite, clay-slate, limestone, sandstone, &c., the upper and newer strata having their edges lower and lower continually". Werner believed that all these rocks were deposited from water, and that the same arrangement or order of succession of the rocks would be found to prevail in all parts of the earth, which might thus be compared to an onion, having coats of rock arranged in a symmetrical order.

But the Edinburgh geologist Hutton soon showed that Werner was mistaken on two points. First, many rocks, such as granite, basalt, &c., Hutton proved to result from the action of heat—to be "fire-formed" instead of "water-formed" in fact—for he was able to point out various sections in the Highlands of Scotland where the granite, &c., could be seen to invade the neighbouring slaty rocks, sending out tongues into them. Moreover, the rocks in contact with the granite usually had a "baked" or hardened and altered appearance. Hutton also showed that the order of succession of the rocks was *not everywhere the same*; *e.g.* he showed that, supposing in one region two beds of limestone were separated by a thick bed of sandstone, it was possible that in a neighbouring region the sandstone might be absent, and might either be replaced by a rock of some other kind, or the upper bed of limestone might rest directly upon the lower.

But there are many beds of limestone, and many beds of sandstone in the crust of the earth; and some of the beds of limestone which are of a very different age, and which occupy in reality very different positions in the succession of the strata, are so much alike in their colour, composition, &c., that it is impossible to distinguish the one bed from the other by the appearance of the stone only; and the same is true of the beds of sandstone, and indeed of almost every other kind of rock.

It was just at this epoch that William Smith, "the Father of English Geology", an English surveyor who had for many years in the pursuance of his calling closely examined the limestones of Somerset and Wilts, and had thence extended his researches over much of England, announced (about 1796) his great discovery that "*rocks can be identified by their fossil remains*". That is, suppose we find an abundance of a certain fossil shell in a rock, in, say, Wiltshire; then, in whatever country we find a rock containing the *same* shell in abundance, that rock will occupy the same, or nearly the same, relative position among the strata, and be approximately of the same geological age as the Wiltshire stratum. This was a key which has since unlocked many geological secrets.

The founding of the Geological Society of London in 1807 was followed in 1815 by the publication of William Smith's Geological Map of England. In this map the strata, or beds of rock, are indicated by different colours, which are seen to run in broad stripes across England, from the south-west to the north-east.

The Geological Survey of the British Isles.—In 1835 Sir Henry de la Beche commenced the Government Geological Survey of the British Isles, a task which is still in progress. This great work consists in indicating by means of coloured maps (first on a scale of one inch, but now also of six inches to the mile) the exact position which every bed of rock occupies on the surface of the country; while, by the publication of horizontal and vertical sections, and of explanatory books called "Memoirs", the relations of the whole series of British rocks to one another are made clear. Every public library ought to (and most do) possess a complete set of the works of the Geological Survey, and each geologist should purchase, at all events, those relating to the part of the country in which he lives.[1]

Equipment for the Field.—It is true that for the study of the rocks as they occur in nature—in cliff and scaur, in quarry and railway-cutting, in roadside ditches and river-banks—a keen pair of eyes, strong legs, and robust health are matters of the first importance—yet the geologist will find that certain articles of apparatus are absolutely necessary; while the possession of a few other implements will enable the work to be done more conveniently, more accurately, and more expeditiously. The principal articles needed by the field-geologist are shown in fig. 2.

1. *Hammers.*—The geologist and his hammer should be inseparable. There are many patterns of this useful instrument, but the most generally serviceable, perhaps, has a head of well-tempered (not too hard) steel, about five or six inches in

[1] A Catalogue of the many hundreds of maps and other publications of the Geological Survey can be obtained (post free, 3*d.*) from the agent, Mr. Stanford, bookseller, Cockspur Street, Charing Cross, London.

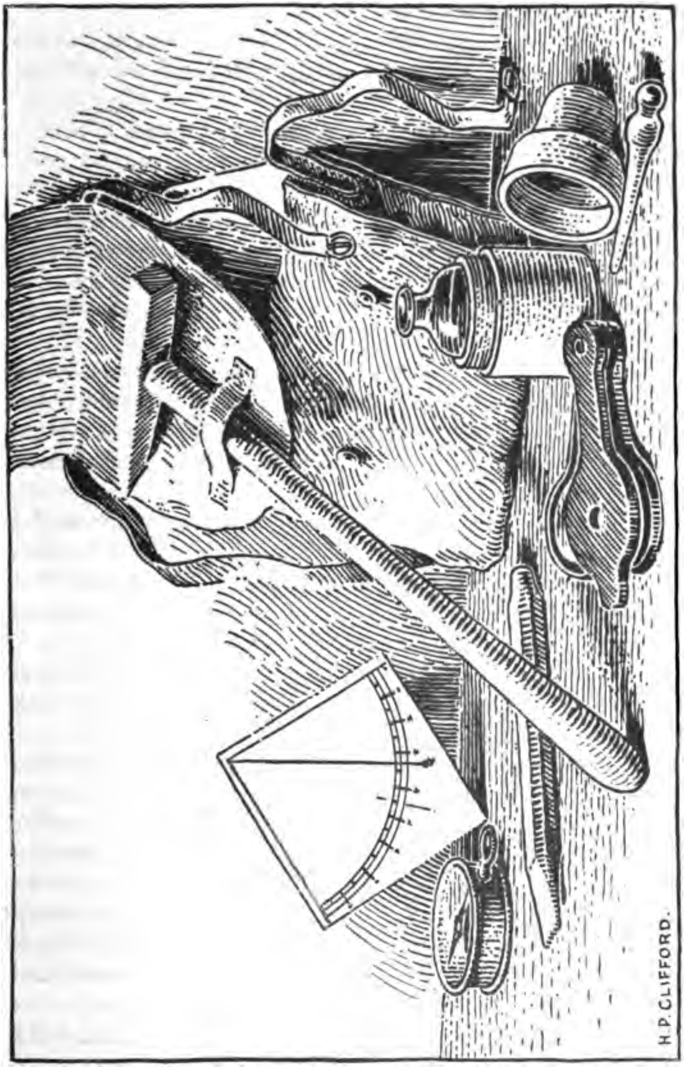


Fig. 2.—A geologist's equipment for work in the field.

length, and having a face about one inch square at the one end, and a horizontal chisel-edge at the other. The shaft should be of ash, and about eighteen inches in length, marked off into spaces of three inches each so that it can be used as a measure.

A small *Trimming-hammer*, weighing about half a pound, and with a steel face about half an inch square, will be found of great service in reducing the rock-specimens to a correct shape and size. For a geologist should always aim at carrying home good specimens of the rocks, and not three-cornered weathered lumps, which are of little service to anyone. A convenient size for hand specimens of rocks is 3½ inches by 2½ inches, by 1 inch in thickness.

For collecting specimens of boulders, and of igneous rocks also, a *heavy* hammer is a necessity. The head should weigh about 5 lbs., and the shaft should be about 3 or 4 feet in length. The head should be removable, so that the shaft may be used as a walking-stick.

2. *Hammer-Belt.*—The hammer may be conveniently carried—and kept from soiling the clothes—by passing the shaft through a slit in a flap of leather attached to a leather belt made to buckle round the waist. This belt may also be fitted to carry other articles, as chisels, &c.

3. One or two "*cold chisels*" (*i.e.* chisels made entirely of iron) are very useful in chipping out fossils from the rock which envelops them.

4. *Maps.*—The maps of the Geological Survey are published in two series; on the scale of one inch, and of six inches, to the mile respectively. These are coloured to indicate the various rocks which occupy the surface. And they are further issued in two forms: (*a*) the "Solid Geology" maps, showing the strata which would actually form the *surface* of the country supposing all the superficial deposits (such as the drift-beds of boulder-clay, sand, &c.) to be removed or swept away; and (*b*) the "Drift" Maps, in which the glacial and other surface deposits are coloured, the "solid rocks" beneath them being only coloured where they actually form the surface (the ordi-

nary "soil" is of course supposed to be removed or stripped off the strata beneath it, in all cases). A full catalogue of these maps can be obtained from the Government agent (see p. 6).

5. *Bag or Wallet.*—To carry specimens in, some sort of a bag or wallet or knapsack is necessary. The satchels made of brown mail-cloth and bound with leather will answer well if the best quality be purchased. A "gamekeeper's bag" of thin leather is very useful; or the bag may be "home-made", in which case it should be of thick grey jean, doubled, and double-sewn all round. The bag should have a *broad* leather strap by which to carry it over the shoulders, and it should be provided with both inside and outside separate pockets in which special objects can be placed.

Each specimen should be wrapped up separately in paper before it is put into the bag; and at the same time a slip of paper bearing the exact locality where the specimen was collected should be inclosed with it. Or instead of this the specimen may be *numbered* (sheets of ready-gummed numbers are sold for this purpose), and the number and locality entered in a note-book.

A few *chip-boxes* lined with cotton-wool should always be carried in which to stow delicate fossils or fragile crystals, &c.

6. *Clinometer.* This is an instrument for ascertaining with exactness the amount of *dip* (as measured in degrees) of any bed of rock. Cut a square of thin wood (the end of a cigar-box will do) or stout cardboard, and by the aid of a pair of compasses describe on it the quadrant of a circle (see fig. 2), dividing the arc so obtained into equal spaces of (say) 5° each. Bore a hole in the corner of the square, and from this hole suspend a small bullet by means of a silk thread. To use the clinometer we have only to place its lower edge upon, or parallel to, the rock-stratum whose slope or inclination we wish to ascertain, and the point where the vertical thread then crosses the arc will give the "dip" in degrees.

7. *Acid Bottle.*—Limestones are easily distinguished from other rocks by their effervescence when in contact with almost any acid. Hydrochloric acid, diluted with an equal quantity

of water, will be found the best for this purpose. It should be carried in a small strong glass bottle, the stopper of which should reach down inside into the liquid, so that a drop of the acid can readily be taken out and placed upon the specimen under examination. This bottle should fit into a small wooden case to prevent its breakage.

8. *Pocket Magnifying Glass.*—The folding form of pocket lenses, in which two or three magnifying glasses are hinged to a horn case is the simplest and most convenient. Such an instrument is very convenient in the field for examining minute fossils, and for distinguishing igneous from aqueous rocks.

9. *Pocket Compass.* A compass—even a small one which can be attached to one's watch-chain—is of special value when walking over any district with which we are not thoroughly well acquainted. It must be remembered that the compass needle does not point to true North, but to a point which lies (in England) about *twenty degrees to the west* of true North. Allowance must be made for this; but in the field it is best to always record in the note-book the actual compass-bearing, and then to make the required correction afterwards at home. The best form is that known as the *prismatic compass,* since this enables us to read off the angle made by any given object with the magnetic meridian.

10. *Tape-measure.*—For accurately measuring the thickness of the strata as exposed in any section, a tape-measure will be required. Small steel tape-measures, which occupy less room than a watch, will be found very convenient.

11. *Note-book and Pencil.*—It is most important to take full notes of each geological section, &c., *on the spot.* The note-book should not be too large—say 5 by 3 inches—and should fit into an inside breast pocket of the coat. A stylographic or fountain pen is much better than a pencil, since pencil-marks are very apt to become illegible.[1]

[1] *Note.*—All the articles mentioned above as useful items in the equipment of the geologist can be obtained from J. R. Gregory & Co., 1 Kelso Place, Kensington, W.; and F. H. Butler, 158 Brompton Road, S.W.

Specimens of all the rocks, minerals, and fossils named in this text-book can also be obtained from these firms.

CHAPTER II.

DENUDATION OR WASTE OF THE LAND AS BROUGHT ABOUT BY MECHANICAL CAUSES.

Waste of Land now brought about by Mechanical Means.—At first sight nothing can seem more permanent than the rocky cliffs, the plains, the hills, and the mountains which form the land. This belief is a most natural one, but it is one which modern geology has shown to be unfounded. The true state of things has been beautifully expressed by Tennyson—

"The hills are shadows, and they flow
From form to form, and nothing stands;
They melt like mist, the solid lands,
Like clouds they shape themselves and go".

The fact is that the land is continually being worn away or denuded by the action of certain great natural agents, which do their work unceasingly and unwearyingly. When we have described their effects the feeling will be one of wonder, not that only one-quarter of the earth's surface is now land, but that there is any land at all, when it is subjected to such continuous and powerful attacks.

AGENTS OF SUBAERIAL DENUDATION.

(1). The Wind.—Of late years an invention called the sand-blast has come largely into use for etching hard, flat surfaces of glass, &c. It consists simply of a quantity of grains of sand propelled by a current of air from a blower. But in nature we see exactly the same thing on a larger scale. In desert and sandy regions, such as the Sahara, the grains of sand are blown against the rocks, which they cut into fantastic shapes and wear away. The force of gravity helping, the general tendency of the wind is to blow matter, as dust, from a higher to a lower level.

(2). Rain.—The proverb says "Continual dropping will wear away a stone", and although the force of a single rain-drop is very small, yet when we remember the countless myriads of drops which fall on the land daily, in some part of the world or another, we shall see that the mere force with which the rain-drops strike the ground must be powerful in loosening and beating asunder the particles of which rocks and soils are composed, and in pushing them down lower and lower. Rock-surfaces of sandstone or limestone which have long been exposed to the rain always bear well-marked furrows. The top of Hampsfell (see fig. 3) shows admirably the eroding action of the rain upon limestone. Much of this action is due to the fact that rain-water contains carbonic acid (dissolved by it out of the air) by which it is enabled to *dissolve* the limestone.

When water-spouts break over the land they may do immense damage, and the great quantity of rain so poured upon the ground almost in a moment sweeps away the soil and vegetation, and sometimes even houses and trees.

(3). Running Water.—No sooner do the drops of rain reach the ground than some unite with one another and trickle over the surface, while others sink into the ground and disappear for a time from our view. The little tricklings of running water from a field or two unite to form rivulets, and the rivulets combine to make rivers, which find their way to the sea.

Every stream of running water denudes and wears away the land over which it passes. It unceasingly *erodes* or excavates both its bottom and its banks, and it transports the matter so eroded to the sea, either *rolled along* on the bottom as pebbles, or *suspended* in the water as mud, or *dissolved* in the water and therefore invisible.

In rainless regions, such as the Colorado Desert of North America, the rivers cut out gorges or ravines with nearly vertical sides (see fig. 4). But where the rain assists in the work, as is usually the case, the sides of the valley are more or less sloping, or they may even be so nearly flat that the river

Fig. 3.—Summit of Hampsfell, near Grange-over-Sands, showing the action of rain upon limestone rocks.

seems to run through a plain. When we compare the great extent of most river valleys with the comparatively insignificant streams which now run through them, we are apt to wonder if it be possible that so small a body of water could have excavated and carried away the many cubic miles of rock

Fig. 4.—The Great Cañon, Colorado.

which must have been removed in order to form each valley. But in geology we have a great reserve of *time* to fall back upon. The world is very old, and the present rivers have probably been running for many thousands of years. Thus, if a river removes only a little solid matter from the land daily (and it certainly does this) we have only to give it *time* enough and it will be capable of doing any work, however great.

By finding (*a*) the average depth and breadth of a river at any given point near the sea, (*b*) the velocity with which the water passes that point, and (*c*) the amount of suspended and dissolved matter which a given quantity of the water, say a gallon, contains, and repeating this experiment at intervals, we can find the total quantity of matter which any given river carries into the sea in a year. But all this matter is removed from the land which the river drains—its *basin* as it is called. Thus we also learn the rate at which the river is *lowering the surface* of its drainage-area or basin.

Taking the Thames as an example, Sir Joseph Prestwich has shown that the amount of matter *dissolved* in the water which passes under Kingston Bridge *daily*, is 1502 tons; of this 1000 tons is carbonate of lime, and 238 tons sulphate of lime; and Sir Arch. Geikie calculates that the amount of sediment (mud, sand, &c.) *suspended* in the water of the Thames, amounts in one year to 1,865,903 cubic feet. All this sediment is swept out by the current of the Thames into the English Channel, and there it sooner or later falls to the bottom of the sea.

In this way the River Thames is lowering the entire surface of its basin at the rate of one foot in 9000 years.

(4). Action of Frost upon Rocks.—Water is an exception to nearly all other substances in the way in which its volume or bulk is affected by the abstraction of heat. When cooled it diminishes steadily in bulk until the temperature of 39° F. is reached. Below this point it *expands* slightly down to a temperature of 32° F. But when this latter point is reached, the water suddenly expands one-tenth of its bulk and becomes the solid we call ice. Thus ten cubic feet of water form eleven cubic feet of ice. It is for this reason that a careful housewife leaves no glass or earthenware vessels containing water exposed to winter frosts. She knows that the freezing and consequent expansion of the water would crack the vessels: for the same reason our leaden water-pipes are often cracked in winter. As an experiment, iron shells several inches in thickness have been filled with water, the hole screwed up, and the shells then exposed to the action of frost. The result

has been that the expansion of the water when freezing has either burst the shells, or has driven out the screw-stopper with great violence (see fig. 5).

The surfaces of all rocks are more or less cracked or fissured: the winter rains fill these cracks, and then the frost turns the rain-water into ice. By the resulting expansion the rock is split and shattered, and the heaps of freshly-fallen stones, which are to be seen in spring at the foot of every cliff, precipice,

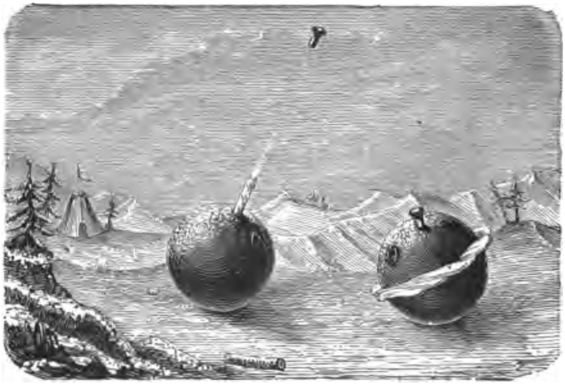


Fig. 5.—Shells burst and exploded by Frost.

and crag, are a tribute to the power of the preceding winter's frost.

Frost also detaches or breaks off, in this way, from the mountain sides and summits, the stones which are continually rolling down upon the surfaces of the glaciers in Switzerland and elsewhere, and of which the *moraines* of these glaciers are largely composed.

(5). Snow.—In regions where the average annual temperature falls below the freezing point, the deposition of water from the atmosphere takes place chiefly in the form of flakes of the soft white solid we call snow. Where the snow is at rest, and while it remains unmelted, it *protects* the rocks beneath it. But when it melts it floods rivers and forms mountain torrents, which may sweep away the soil and loose rocks, together with

houses, trees, &c. In such countries as Switzerland the snow is often suddenly detached from the mountain sides in summer in large masses, and these roll down as *avalanches*, which are well known to do great damage.

When snow falls in a partly-melted state it adheres to the leaves and branches of trees, and may break them down by its accumulation. The forests of northern countries are often greatly damaged in this way.

(6). Glaciers: their Nature and Action.—The snow that falls on the higher parts of cold countries accumulates on the high lands to a considerable depth, and becomes consolidated by its own weight, and by alternate thawings and freezings, into a whitish mass half snow and half ice, called in Switzerland *névé* or *firn*. This névé is slowly drawn down the valleys by the force of gravity, and is at last converted by its own pressure into a great stream of blue transparent ice which creeps down the valley like a river, and is called a *glacier*.

A glacier is, in fact, a river of ice. Its rate of motion varies from a few inches to many feet each day, being most rapid in summer. It is crossed by numerous cracks called *crevasses*, some of which reach down to the bottom of the glacier. The surface of the glacier is more or less covered with angular lumps of rock detached by ice from the surrounding mountain sides. These rocks form lines or heaps along each side of the glacier, which are called *lateral moraines* (see fig. 6 *a*). Should two glaciers unite, a *medial moraine* will be formed by the junction of the two inner or adjacent lateral moraines (see fig. 6 *b*). The ice composing a glacier rubs with great force the rocks over and between which it passes. Its action in this respect is aided by the stones which, falling down the crevasses, are frozen into the ice at the bottom of the glacier, and then act like so many chisels, cutting, scoring, and scratching the subjacent rocks. The debris which in this way accumulates *underneath* a glacier (and which is steadily pushed onwards by the ice) is called the *ground moraine*.

Within the polar circles some of the glaciers reach down to the level of, and enter the sea. The buoyancy of the sea-

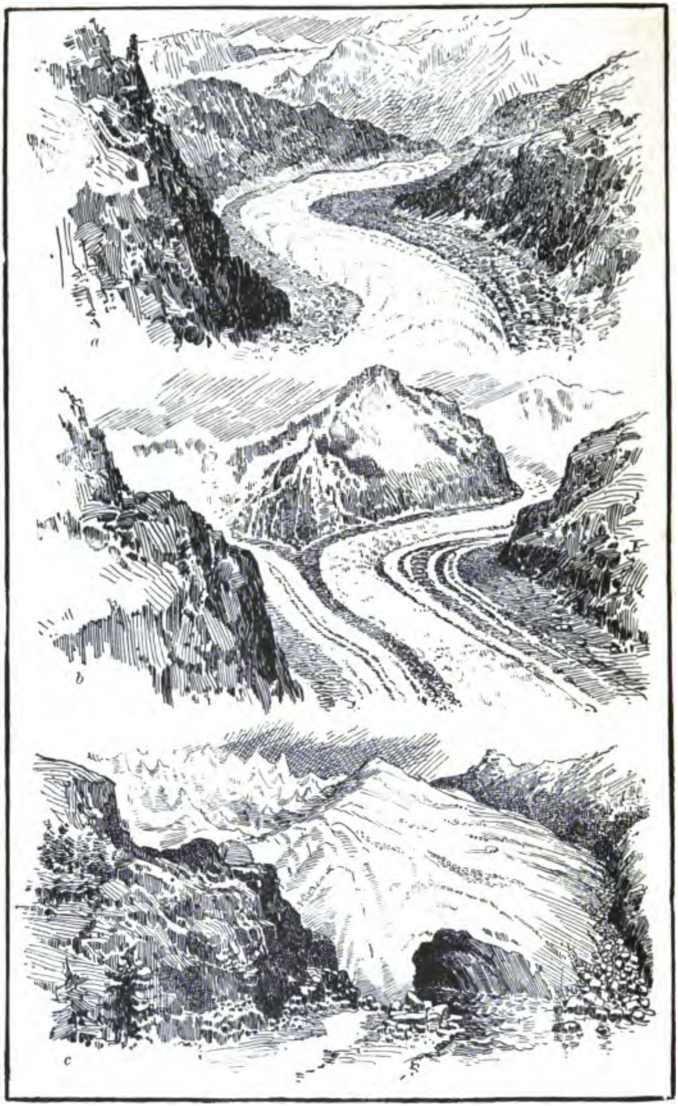


Fig. 6.—Glaciers and Moraines.

***a*, Mer de Glace (Mont Buet), showing lateral moraines; *b*, Schienhorn and Ober-Aletsch Glaciers meeting and forming medial moraine; *c*, Glacier of Zermatt, showing terminal moraine and ice-cavern.**

water then breaks off immense pieces of the snout of the glacier, which float away as icebergs, carrying with them the stones, earth, &c., which have been transported by the glacier as part of its moraines. As these bergs float towards the equator and enter warmer water they gradually melt, and the matter they carry then sinks to the bottom of the sea.

But the glaciers of the Alps, Himalayas, &c., push down their valleys far below the snow-line into warmer air, by which they are at last melted. Where the glacier ends we usually find a horse-shoe-shaped accumulation of rubbish—the stones, &c., brought down by the glacier—called a terminal moraine (see fig. 6 *c*). Through this terminal moraine, and often issuing from an ice-cavern contained in the 'snout' or tip of the glacier, there is sure to run a stream of muddy water, resulting from the melting of the ice. By measuring daily the quantity of the sediment in any glacier-river it would be possible to estimate the rate at which the glacier is wearing away the rocks over and between which it passes.

MARINE DENUDATION.

The Sea as an Agent of Denudation.—The erosive or wearing-away action of the sea is necessarily limited to coast-lines, and may be said to be confined to a vertical space of about 200 feet below and as much above low-water mark. It is, of course, only when the sea-water is in fairly rapid motion that it can act destructively upon the crust of the earth, and at a greater depth than 200 feet the force of the surface waves is not felt. The denuding agency of the sea has been well compared to the action of a horizontal saw, everywhere cutting into the land along coast-lines, wearing away, breaking up, and removing the land, and causing the debris to be spread over the floors of the seas (see fig. 7). The force of the waves in storms is very great. On the west coast of Scotland blocks of stone on the beach up to 50 tons in weight have been moved by storm-waves; while at Unst, the most northerly point of Shetland, walls were overthrown and a door was broken open by the waves at a height of 196 feet above the sea.

Fig. 7.—Breaking Wave at Pen-y-Chain, near Criccieth, Carnarvonshire.

The blocks broken off by the action of the waves, and detached by frost, &c., from the cliffs, are used as missiles by the sea-water to break down the rocks which compose the coasts exposed to its fury. The sound of the shingle dashed against the cliffs can in some places be heard miles from the shore in stormy weather. The softer rocks are thus worn rapidly away, and form bays and inlets, while the harder strata stand out as promontories and capes.

Fig. 8.—Rocks on Coast being worn away by the Sea.

The magnificent cliffs of the west coasts of Scotland and of Ireland are the best places to visit to receive ocular demonstration of the erosive power of the sea. But in reality the low coasts of Norfolk and Suffolk, and of that part of Yorkshire between Flamborough Head and the Humber, are receding much more rapidly before the marine onslaught than the loftier and harder rocks of our western shores. The advance of the sea along the east coast of England is believed to amount on an average to at least three feet per annum, and the sites of many towns and villages which flourished during the middle ages now lie beneath the waters of the German Ocean (see fig. 8).

CHAPTER III.

How Rocks are Formed out of Rocks.

Origin of Boulders.—The word 'boulder' originally meant any block of rock naturally lying loose upon the ground or embedded in the soil. Geologists use the word with the restriction that the block must have been *transported from some distance.* For instance, the action of the weather may first loosen and finally detach a block of granite from the surrounding granitic mass. By its superior hardness, or by an accident of position, this block may be left isolated on the top of a hill, forming a part, it may be, of a Cornish 'tor', or even becoming one of the logans, or rocking-stones, not uncommon in that county. We should not, however, in geology, apply the term 'boulder' to this detached mass of granite, mainly because it has never been shifted from its original position.

But if we can imagine a great glacier to descend from Scotland, in which a block of Scottish granite, becoming embedded in the ice, is transported by it to (say) Wolverhampton, and left there stranded on a clay hill, we should then consider this block as a true boulder, for it would have travelled far from its native home. In this way ice (as glaciers and icebergs), snow (in avalanches), and rivers when in flood, have broken off or lifted masses of rock sometimes of great size and weight, and transported them to varying distances.

As a famous example of a boulder we may mention the block of gneiss ("*Pierre à Bot*" the peasants call it), weighing 3000 tons, which lies two miles west of Neufchatel. The stone can be identified with the gneiss of Mont Blanc, and it must have been carried by ice for at least sixty miles. All over the British Isles north of the valley of the Thames similar (though much smaller) boulders can be found, varying from one or two feet to several yards in diameter. The great majority of these boulders have been transported in a southerly direction, and many of them can be identified with the rocks of Scotland, of

North Wales, and even of Scandinavia. They were probably carried on or in glaciers during the last glacial period.

Formation of Rounded Pebbles.—The blocks of stone freshly detached from sea-cliffs by the action of the waves, or from crags by frost, have their corners more or less sharp or angular. Those which fall upon sea-beaches are daily moved up and down by the tides, and are rolled over and rubbed against each other in a way which wears off their corners and projections and soon reduces them to rounded lumps called *pebbles* (see fig. 9).

In the same way the heaps of freshly-detached angular stones found every spring-time at the foot of each crag or precipice,

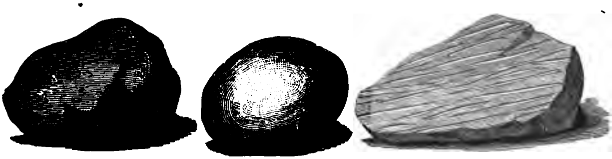


Fig. 9.—River-worn Stone. Wave-worn Stone. Stone worn by Glacier.

in time become rounded into pebbles by the action of running water. Every shower of rain pushes them a little further down the mountain slopes and hillsides. Soon they fall into little rivulets, and by them are conveyed into rivers. On the river-bottom these stones are rolled over and over, and dashed one against the other; and they are thus gradually reduced in size and in angularity, until finally they are carried into the sea. It must be remembered that stones when in water weigh only about half as much as in air, hence they are much more easily rolled along. A river whose current has a velocity of two miles per hour can sweep large pebbles along its bottom; and although these are usually invisible to observers from above, yet the noise of their jolting one against another at the bottom of such rivers as the Rhine can be heard when we lie down in a boat and place one ear against the wooden floor.

Rounded pebbles are also often formed in shoal-water, at some distance from the land. In such places, where the sea is only a few feet in depth, and where conflicting currents meet,

or tides run, extremely well-rounded pebbles may be, and often are, formed.

Disintegration of Rocks into Minute Particles—Formation of Sand and Mud.—Every time one pebble is knocked against another, as on a sea-beach, river-bottom, or shoal, small portions of each stone are broken off. Suppose we have a number of granite pebbles hurled together by the sea on some Cornish beach. Now, the granite is composed of distinct crystals of three minerals—quartz, felspar, and mica. When it is broken up or comminuted by the waves, the quartz will form grains of *sand*, while the felspar and the mica will be separated into extremely small and light particles, which will be swept to a great distance by the currents, and which in the end will settle down in some quiet depth of the sea to form a bed of *mud*.

It is the same in every river; great numbers of the pebbles conveyed by the river are completely broken into small pieces long before the river reaches the sea, and it is these small particles of decomposed felspar and of similar minerals which give to many rivers a muddy appearance. At last all the contents of a river are swept out into its estuary. The heavier pebbles sink at once, forming shoals near the mouth of the river; though they, too, may be removed to a distance if strong currents or tides chance there to run parallel to the coast-line. The grains of sand are also rather heavy; they sink to the sea-bottom and may form sand-banks at a somewhat greater distance from the coast. Finally the extremely small and light particles of clay, mica, &c. (the 'mud') may be carried out many miles to sea, before they, too, find their resting-place at its bottom.

In this way the action of gravity, combined with the mechanical force of moving water, disintegrates the solid rocks and *sorts out* the materials of which they are composed. Then at some future day, if elevation of the sea-floor takes place along that coast-line, we shall have a bed of conglomerate (the pebble-bed) in one place, a bed of sandstone next to it, and of shale (hardened mud or clay) next to and beyond this.

Detritus Carried in Mechanical Suspension in Rivers.—Rivers derive their waters from three sources—(1) rain, (2) the melting of snow, (3) springs. The flow of water in a river continually wears away both the banks and the bed or bottom. Moreover, every rainfall produces thousands of tiny rivulets, each of which carries its tribute of detritus—stones, sand, and mud—into the main stream. Thus rivers are continually excavating and widening the valleys along which they flow.

To calculate the amount of detritus or sediment carried in mechanical suspension by any river, we must determine (*a*) the average volume of water which passes any given point per day, and (*b*) the average amount of solid matter held in suspension in each gallon of the water. We must be careful to distinguish the visible matter held in *suspension* from the invisible substances contained in *solution*. The former can be estimated by taking a gallon of the water and allowing it to stand till all the solid matter has sunk to the bottom. The water must then be carefully poured off, and the sediment dried and weighed. But we must not forget to also reckon the solid matter—pebbles, &c.—pushed and rolled along on the bottom of the river.

From many experiments the average quantity of solid or suspended matter carried along by a river is found to be about the two-thousandth part of its volume. Careful and long-continued observations on the River Mississippi show that this stream annually conveys in suspension 370 millions of tons of mud into the Gulf of Mexico, in addition to 750 millions of cubic feet of gravel, &c., which are pushed along on the bottom of the river.

Cementing Substances in Rocks.—When the detritus brought down by rivers or glaciers, or washed by waves from off coast-lines, sinks to the bottom of the sea, it is naturally loose, soft, and incoherent; being for the most part in the state of either sand or mud. Yet we believe that nearly all the stratified rocks—all of which are more or less hard—were formed in this way upon the floors of seas or lakes. What

then are the cementing substances which bind together and harden rock-forming materials, and how were they introduced?

For one thing, *pressure* alone will do much to consolidate a rock. And all rocks have been subjected to pressure. Not one bed only of sand or of mud has been laid down on the sea-bottom, but bed upon bed, each new stratum pressing down and upon those underneath it. In this way (by pressure alone) sand can be changed into sandstone, mud into shale, and peat or other vegetable matter into coal.

But in addition to pressure there are various natural cements which bind together the particles of rocks, just as glue holds two pieces of wood together. Of these natural cements, the three most commonly met with are:—(1) carbonate of lime, (2) silica, and (3) peroxide of iron. All these cementing substances were originally contained in solution in the water (often warm or hot) which percolated through the stratum, and while so doing deposited some of the matter which it held in solution on, around, and between the individual grains or particles so as to cement and bind them together.

If the cement is carbonate of lime ($CaCO_3$) it can be detected by the evolution of carbonic acid gas (and consequent bubbling-up or effervescence) which takes place when a little dilute acid is poured on the rock.

Peroxide of iron (Fe_2O_3) colours rocks yellow, red, or brown; it is a common cement in sandstones.

Silica (SiO_2) is another cement of frequent occurrence in sandstone. In a thin slice of sandstone when examined under the microscope we can often distinguish the original rounded grains of sand, and notice that the spaces between the grains are filled up with a hard clear matter, which is deposited silica. Acids have no effect upon it.

Formation of Marine Deposits by Mechanical Deposition of Detritus.—We may class marine deposits of sediment under two heads: first, those laid down in comparatively shallow waters, the depth not exceeding say 1000 feet (these are known as *terrigenous deposits*); and secondly, those which are formed in greater depths—such ocean depths

reaching as we now know to 30,000 feet (these are known as *pelagic deposits*)—see fig. 10, Charts I. and II.

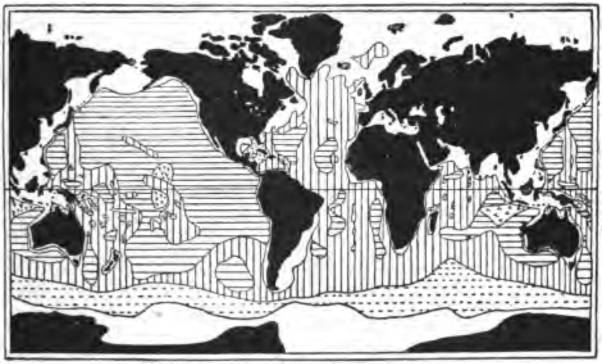


CHART I. OCEAN DEPOSITS. White space bordering lands, Terrigenous deposits; vertical lines, Globigerina ooze; horizontal lines, Red clay; broken horizontal lines, Diatom ooze; two areas marked V are Radiolarian ooze; dotted spaces, Coral sands and muds; a few white spaces, Pteropod ooze

(Reproduced from "Knowledge," March 1, 1893.)

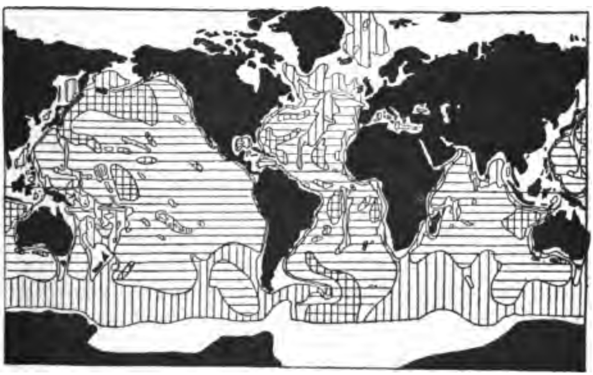


CHART II. OCEAN CONTOURS. White space bordering lands, shallow waters up to 1,000 fathoms; vertical lines, 1,000 to 2,000 fathoms; horizontal lines, 2,000 to 3,000 fathoms; squares, 3,000 to 4,000 fathoms; fine cross, over 4,000 fathoms.

(Reproduced from "Knowledge," March 1, 1893.)

Fig. 10.—Ocean Charts: showing in Chart I. the nature of the deposits on the sea-floor at varying depths; and in Chart II. the contours or varying depths of the oceans.

The shallower water of course fringes the coast-line, extending to distances of twenty or sometimes fifty miles from

the shore, while the extreme depths occur at a further distance from the mainland, in the great oceans.

The greatest depth as yet reached by the sounding line is nearly six miles in both the Pacific and the Atlantic Oceans. The average depth of these oceans is about three miles.

Our knowledge of the floors of the oceans extends back only some forty years, and dates from the time when a chain of soundings was made across the North Atlantic to discover whether its floor was a suitable resting-place for the Anglo-American telegraph cables.

1. *Terrigenous Deposits.*—An important limit is marked by the "hundred-fathom line" (= 600 feet) which is indicated on many maps. Up to this depth shelly sands and even shingle beds occur, and this depth may be said to mark the limit of the littoral or shore deposits.

At greater depths—say from 100 to 700 fathoms (a fathom = 6 feet)—a blue, green, or reddish mud is the usual deposit upon the ocean-floors.

2. *Pelagic Deposits.*—At still greater depths—5000 to 12,000 feet—beds of *ooze* occur, which are described further on (see pp. 30 and 31).

Lastly, at the greatest depths from which specimens have been brought up—12,000 to 30,000 feet—we find peculiar red and gray clays, which are probably the result of the decomposition of volcanic felspathic minerals such as occur in pumiceous matter. In these deep-sea clays lumps or nodules of peroxide of manganese occur (see fig. 10, Chart I.).

Formation of Stratified Deposits in River Estuaries.—Many rivers broaden out where they enter the sea into a wide expansion, called an estuary. A glance at a chart or map of the mouth of such a river, like the Thames, the Mississippi, or the Ganges, will show a shallow sea near the estuary, and both the estuary and the adjoining sea will be seen to contain shoals and sand-banks, which constitute a source of danger to ships entering or leaving the river. These shoals and sand-banks are composed of detritus brought down from the interior by the river, which is thus continually forming new land and

pushing its mouth further out to sea. In this manner all Lower Egypt (which has an area of 12,000 square miles) is composed of mud and sand—which some recent borings have penetrated to a depth of several hundreds of feet without reaching the hard rock—brought down during past ages by the River Nile. Thus the well-known saying—that "Egypt

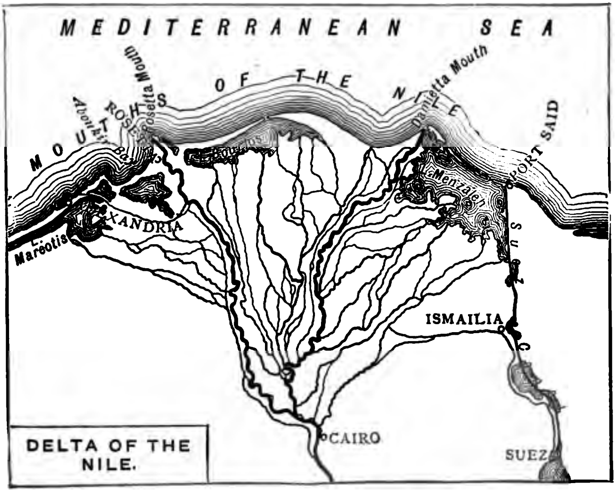


Fig. 11.—Delta of the River Nile.

is the gift of the Nile"—can be shown to be geologically correct (fig. 11).

These estuarine deposits frequently show false-bedding (see fig. 14) owing to the action of opposing currents and tides; and they contain a very mixed assemblage of fossils, including many fresh-water and land species of animals and plants swept down by the river, other brackish-water species proper to the place, and perhaps a few marine creatures brought in by the advancing tides.

Salt-water has a remarkable influence in causing sediment to sink more rapidly, and this contributes to the rapid formation of sand and mud banks near the mouths of rivers.

Deposition of Stratified Rocks in Lakes.—Lakes have been compared to filters, or places wherein the water of rivers becomes strained or cleared. Thus the River Rhone enters the Lake of Geneva as a turbid and muddy stream, but its waters are clear as crystal where it quits the other extremity of the lake. The Rhone deposits most of its sediment near the end of the lake where it enters, and where the velocity of its current is suddenly and greatly diminished. The result is that a delta is being formed, and that the lake is much shallower at this end. In time it is evident that the lake will be completely filled up and will form a plain. Many such plains—old lakes filled up with river sediment—exist in different parts of England.

This action—the filling up of lakes with sediment deposited by the rivers which traverse them—must also have gone on in bygone days; and by the fossil contents—shells and plants somewhat similar to those which now inhabit fresh water—we can identify lake-deposits in several British formations. For example, the "Bovey Tracey Beds", near the village of that name in Devonshire, contain very numerous remains of land-plants, and a fossil insect.

ORGANICALLY-FORMED ROCKS.

1. Foraminiferal Deposits — Chalk. — The numerous deep-sea soundings made between 1843 and 1856 showed the bed of the North Atlantic Ocean between Ireland and Nova Scotia to be chiefly composed of a whitish mud or ooze, the average depth being about 12,000 feet.

This ooze when examined under the microscope was seen to be largely composed of the minute shells of tiny animals, called *foraminifera.* In our ordinary white chalk we have an example of a rock deposited in the same way at a time when much of what is now Europe formed part of an ocean floor.

The foraminifera inhabit the surface waters of the ocean: when they die their hard coverings or shells (formed of carbonate of lime) sink to the bottom and there form a white ooze, which may subsequently, when hardened and consolidated, form a rock

resembling chalk. Hence it is probable that chalk is a deep-

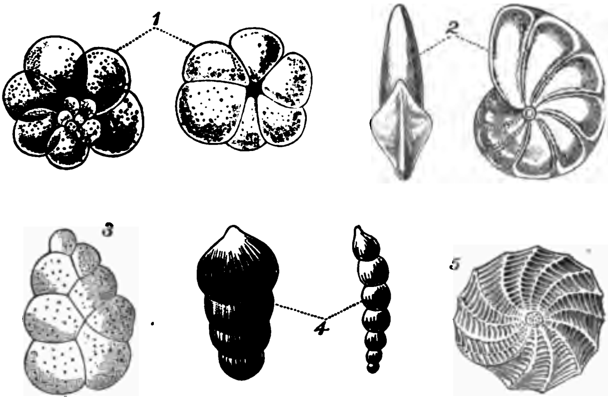


Fig. 12.—Shells of Foraminifera.

1, Globigerina. 2, Cristellaria. 3, Textularia. 4, Nodosaria. 5, Polystomella.

sea deposit. It is certainly an organically-formed rock, since it is composed of the remains of organized beings (see fig. 12).

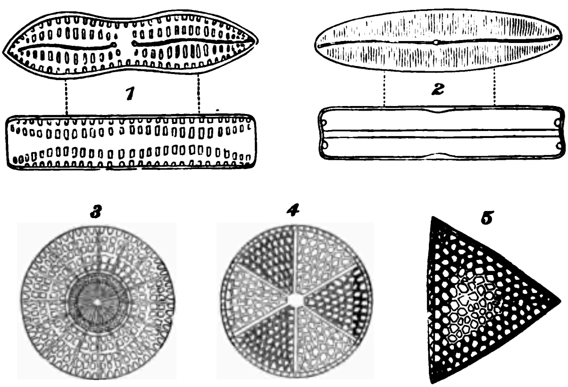


Fig. 13.—Skeletons of Diatoms.

1 and 2, Navicula. 3, Arachnoidiscus. 4, Actinocyclus. 5, Triceratium.

2. Diatomaceous Ooze.—A diatom is a microscopic plant which forms for itself a hard covering of silica. Like most

small organisms it makes up for its want of size by occurring in great numbers. It often happens that the deposit at the bottoms of shallow seas or lakes, which appears to the eye like a grayish mud or ooze, is found when examined with a microscope to be composed of countless numbers of diatoms and other similar organisms. That such creatures played a like part in the past is proved by the occurrence of layers of 'tripoli' or 'infusorial earth' (composed of their remains) in the rocks of certain countries. When powdered, such material forms a valuable substance for polishing metals, rocks, &c. (see fig. 13).

3. Coral Reefs.—In the warm waters of tropical seas the reef-building coral polyp forms its hard part or skeleton of carbonate of lime, secreted or abstracted by the animal from the sea-water. By the growth of one generation of polyps upon another, *coral reefs* are slowly formed, many of which are of great extent and thickness. Similar old beds of coral are found at various horizons or levels in the stratified rocks, not only in countries now within the tropics but in temperate and even in arctic regions; proving either a warmer climate in those days or that the habits of the coral animal were somewhat different. Perhaps both causes co-operated to admit of this former greater extension of coral reefs.

4. Shell-beds.—Several species of shells—oysters, mussels, and cockles, for example—congregate together in groups or beds on the floors of shallow seas. Many examples of similar *old* shell-beds contained in certain rocks are known. Thus an oyster-bed formed during the Oolitic period, and now known as the *Cornbrash*, can be traced from Dorset into Yorkshire, its thickness throughout its course being about twelve feet.

5. Beds of Coal and Peat.—Plants, too, have contributed their share towards the formation of stratified rocks. Our *coal-seams* are the compressed remains of the mighty jungles and forests which covered England during the Carboniferous epoch.

Peat is a vegetable product of comparatively recent origin, produced by the continuous growth of certain species of mosses in damp localities.

Thus we learn that no small portion of the crust of the earth

has in bygone days formed part of some living thing, either animal or plant.

CHAPTER IV.

Stratified or Aqueous Rocks.

Proof that the Stratified Rocks generally were formed by Deposition from Water.—One of the greatest of modern geologists, the late Sir Charles Lyell, steadily enforced the principle that we must *explain the past by the study of the present.* Thus if we meet with any remarkable or puzzling appearance in the rocks, the best way to its explanation is to seek for something similar now in course of formation. Then the causes which have produced the one will probably also be those which have originated the other. That is, in studying the rocks we are to rely mainly on observation and experiment, and not on theory.

Now, what proofs have we that the stratified rocks which form ninety-nine hundredths of the crust of the earth have been formed by deposition, as sediment, in water?

1. Stratification.—In the first place, the rocks in question are *stratified.* When sedimentary matter sinks down to the bottom of the water in seas, rivers, or lakes, each particle of mud, &c., arranges itself with its longer axis parallel to the surface upon which it rests. The result is the formation of a succession of layers constituting a stratum or bed.

2. Alternations of Strata.—Any careful student of a series of rocks belonging to one and the same geological set or formation will probably find them arranged in the following order: First (that is, lowest down, or at the bottom of the series), a conglomerate or breccia, containing large lumps of stone; next, a sandstone; and then a shaly or slaty rock formed of hardened mud. Now this is just the order in which such strata would be deposited, one upon the other, on a steadily sinking sea-floor. The conglomerate would be formed as a

shingle-bed on or near the shore; as the coast-line receded, sand would be deposited in the same place; and, finally, as the distance from the margin of the land became considerable, mud only would be brought to that spot.

Deposition in just the reverse order to that described above would take place in regions where *elevation* was going on.

3. Diagonal or Cross Stratification.—The false-bedding seen in certain rocks (fig. 14) is just what we find nowadays to be produced in lakes and estuaries, and wherever currents sweep sediment first in one direction and then in another. Hence it is also known as "current-bedding". But since the same appearance is produced in the sands of deserts by the action of the wind, and beneath glaciers by the streams of running water which there occupy channels in the ice, it requires the evidence of marine shells, remains of fishes, &c., in the same strata to absolutely convince us of the deposition of these "cross-bedded" rocks in open water; and this evidence is frequently not wanting.

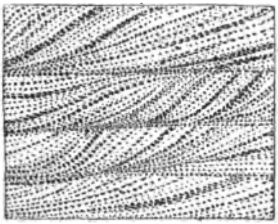


Fig. 14.—False-bedding; also known as Oblique Lamination, and as Diagonal or Cross Stratification, and as Current-bedding.

4. Fossils.—The fossils so plentiful in rocks are for the most part the remains of the hard parts of animals and plants which inhabited the waters of seas, rivers, and lakes. When the remains of land plants and animals occur as fossils they appear in most cases to have been swept into the sea by floods, rivers, &c. As a matter of fact, it may be said that nine-tenths of the fossils we find in stratified rocks are of *marine* species.

In most cases it is evident that the shells, &c., found in the rocks, lived where they are now found. The beds of fossil oysters, mussels, cockles, &c., are clearly resting on their original places of growth. The encrinites or "sea-lilies" are still embedded in the (now hardened) limy mud in which they were first rooted.

5. Rock-markings.—The ripple-marks, sun-cracks, foot-prints, &c., seen in many rocks give evidence that these rocks were once soft sands or muds forming some old beach on which the tides rose and fell, the sun shone, and over which animals crawled or walked about.

Successive Deposition of Strata.—The total thickness of the stratified rocks, which are known to us as forming part of the crust of the earth, is about 100,000 feet or twenty miles.

In no one district are *all* the stratified rocks to be seen in their due succession; in no single *section* can we examine even the tenth part of this great thickness. But if in one quarry, say, we can see that a given rock (A) overlies another rock (B), and in a second quarry B overlies C; then we know that the rock A must also overlie and be of later origin than C.

Fig. 15.—Strata thinning out and overlapping each other as they approach a shore-line *c*: *a* and *b*, bands of limestone, above and below which come beds of shale and sandstone.

Nearly all the stratified rocks were formed by the slow and steady deposition of sediment in water; for the most part in the water of shallow or moderately deep seas (see fig. 15).

The *average* thickness of the sediment deposited on the floors of seas during each year has been estimated at the fiftieth part of an inch, and at this rate the whole of the series of strata with which we are acquainted could have been deposited in fifty millions of years.

But this estimate would be far too small; for we know that there are great *breaks* in the succession of the rocks, and that they were *not* deposited in a continuous and unbroken manner. It is, indeed, believed that the period of time unrepresented by any existing geological deposits or strata is and must be greater than that during which the existing strata were actually deposited. Thus there are *many missing chapters in the geological record*, and it must ever remain imperfect.

A striking proof of the fact that distinct beds of rock were formed at distinct epochs or times is shown by the fact that numerous unconformities (see p. 64) exist between the respective strata. If all the beds of rock had been formed simultaneously, or successively without any breaks, all the strata would lie upon and parallel to one another, from the oldest to the newest. But there can be no doubt but that the rocks formed during any one period of the earth's history were often hardened into stone, then elevated to form land for an indefinite length of time, and then again depressed to form some sea-floor upon which more sediment (to form newer rocks) was deposited during a later period. Yet of the long interval that must necessarily have elapsed between the formation of these two sets of strata, we should—in that locality at all events—have no record.

Each Stratum has its Characteristic Fossils.—The student who means to understand the nature of the fossil remains of animals and of plants which occur in most of the stratified rocks, will find it necessary to study both Zoology and Botany.

The animals which now inhabit the earth can (as a rule) be obtained and studied far more easily than those whose remains are embedded in the rocks, for we can examine both their hard and their soft parts, their skeleton and their flesh, while the fossils retain their hard parts only. Moreover, fossils are commonly *very imperfect*; we find only a tooth, or a single bone it may be, and from that have to reconstruct in imagination the entire animal.

A knowledge of Zoology, the science which studies the animals that now inhabit the earth, is therefore necessary to the student of *palæontology*—the science which studies the life of the past. A knowledge of Botany must be included if we mean to study fossil plants.

The researches of geologists have now brought to light a great number of fossils, and palæontologists have distinguished and named many thousands of species of fossil animals and plants.

Now, these fossils are not spread indiscriminately throughout the stratified rocks. It was the great discovery of William Smith about 1796, that each set of strata, each formation, is distinguished by the presence of a certain assemblage of fossils which are peculiar to itself. Thus the fossils of the Silurian rocks differ both from those in the Ordovician rocks which lie just beneath them, and from those which occur in the Devonian strata next above. There are some fossil shells—the Ammonites, for example—each species of which occurs only in a thin stratum of rock of a particular age. Thus the fossil called *Ammonites planorbis* is found only in the lowest beds of the Lias or Liassic formation; and wherever this fossil occurs, whether in a quarry in Leicestershire, a railway-cutting in Germany, or a Russian hillside, it would be evidence to the skilled geologist of the exact geological age of the stratum in which it was found.

Thus a fossil may have an unlimited range *horizontally*, because in all countries the beds which contain it were probably formed at or about the same time. But the *vertical* range of each fossil species is more or less limited; and the more highly organized the creature, the more characteristic of one particular stratum it is certain to be.

CHAPTER V.

STRATIFIED ROCKS—(*continued*).

Tests of the Relative Ages of the Stratified Rocks.—In geology we are not able to lay down any scale of time of years; or, at all events, our estimates of this kind can only be considered as rough approximations.

We know exactly how many years it is since the death of Shakespeare, or the landing of William the Conqueror. But beyond knowing that it is a very long time—a period to be measured in millions of years—we cannot say how long it is since the chalk cliffs of Dover were deposited as ooze on the

bottom of some ocean; or, earlier still, how many years have elapsed since the compressed vegetable matter which forms our coal-seams grew as dense forests over what is now England.

But in the great mass—above twenty miles in thickness—of the stratified rocks, we can distinguish about fifteen principal sets or divisions, or *formations*; each of these great formations, again, has its subdivisions; and so on.

It is one—and a very important—object of the geologist to arrange all these strata according to their *relative ages*, so that the order of succession of the rocks shall be known from the oldest to the newest.

The following are the principal tests by which the comparative ages of strata are ascertained:—

1. **Superposition.**—Of any two undisturbed beds of rock, that which lies underneath must be the older. We may compare this to a pile of books lying on a table: the bottom book must have been put down first. Take the Carboniferous Formation as an example. In it we find the coal-seams, with their associated layers of shale, &c., to be underlain by a thick mass of sandstone (the *Millstone Grit*), and beneath this again is a still thicker deposit of limestone (the *Mountain Limestone*). Geologists believe that this last-named deposit tells us of a clear sea in which the limestone accumulated. In the Millstone Grit we see evidence of the shallowing of this sea; and, finally, the coal-seams indicate the elevation of the old sea-floor

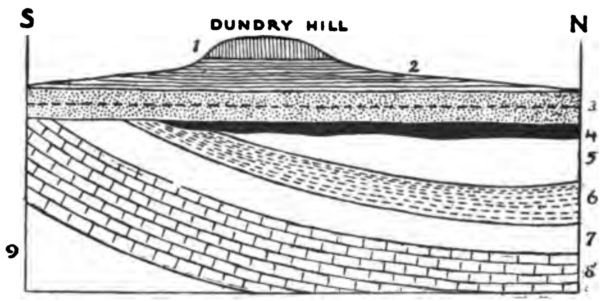


Fig. 16.—Section near Bristol showing the Trias (Nos. 3 and 4), Lias (2), and Oolite (1), resting unconformably upon the Carboniferous Strata (5 to 8) and Old Red Sandstone (9).

above the level of the sea, thus forming a surface on which land-plants could grow (see fig. 16).

Of all the tests of the relative ages of the stratified rocks, this test—superposition—is undoubtedly the clearest and the most satisfactory when the rocks occupy their normal position, *i.e.* where they have not been disturbed or folded or inverted.

2. Included Rock-fragments.—If one stratum or bed of rock contain fragments of another, it must be of later formation. This test is sometimes useful in regions where the strata have been much disturbed by volcanic forces, so that they are now standing on end, or may even have been inverted.

3. Nature of the Included Fossils.—The more recent or younger a rock is, the greater will be the resemblance of the fossils which it contains — the remains of animals and plants—to the life of the present day. In the latest-formed strata—the river muds and sand-beds of the present day—*all* the fossils can be identified with living forms. The shells are all precisely similar to living shells, the bones to the bones of living animals, the plants to still growing plants; that is, they are all of recent species. In rather older rocks we find a *few* fossils not exactly like anything which now lives, and which we therefore call *extinct* species. As we pass to still older rocks the proportion of extinct species increases, until at last *all* the fossils found are of this class. Then in older strata still, not only are all the fossils of this extinct kind, but many of them are *extremely unlike* anything now living upon the earth. Thus the fossils of any stratum give a clue to its relative age.

IGNEOUS ROCKS.

Igneous, or Eruptive Rocks.—Although stratified rocks, composed of sediment deposited in water, form by far the greater part of the crust of the earth, yet here and there we find other rocks that have as certainly cooled down from a molten state, and to these the term *igneous*—fire-formed—is applied. Because these igneous rocks are usually found to

break through or cut across the sedimentary strata which surround them, they are also called *eruptive.*

These igneous rocks are the result of volcanic action during former periods of the earth's history. Some of them are old lava-streams; others are masses of deep-seated melted rock which lay beneath old volcanic cones, but which never saw the light of day while in the molten state. But that old volcano has since been worn down to its base; the materials composing its crater and even its cone have been broken up and washed away, and its roots, so to speak, have been bared and exposed. Granite and syenite are examples of such old and deep-seated

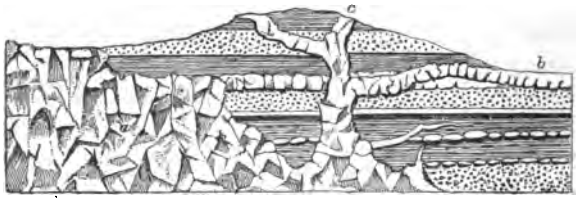


Fig. 17.—Igneous Rocks *a*, *c*, *b*, breaking through and intruding on Stratified Rocks. The gneous rock at *c* breaks through the sandstones, shales, &c., nearly at a right angle; but the intrusive band *b* has forced its way laterally, and lies almost parallel to them.

igneous rocks; while the igneous rocks called basalt, trachyte, &c., represent the old lava-streams (see fig. 17).

These igneous rocks are usually found cutting through, or breaking across the sedimentary or aqueous rocks. Near the junction the latter rocks have usually a baked, altered, or metamorphosed appearance, due to the great heat to which they were subjected by the vicinity of the molten mass.

True igneous rocks of course contain no fossils,[1] and although they sometimes have a banded appearance they are not stratified. They are usually heavy, hard, and compact. They are also usually *crystalline*, the crystals in some—as granite—being so large as to be plainly visible; while in other varieties they are only to be seen when thin slices of the (igneous) rock are examined under the microscope.

[1] There are, of course, "exceptions to every rule", and a very few cases are known in which old lavas, etc., have been found to enclose traces of once-living things—as a portion of a tree-stump, etc.

SECTION B.—COMMON GEOLOGICAL TERMS.

CHAPTER VI.

THE CRUST OF THE EARTH; AND THE ROCKS WHICH COMPOSE IT.

"Crust of the Earth."—During the first half of the present century the idea entertained by most scientific men as to the condition of the earth, was that the interior was intensely hot, and more or less fluid, and that this fluid interior was surrounded and inclosed by a comparatively cool and solid "crust", whose thickness was estimated by some geologists as ten, and by others as about twenty miles.

But the mathematical researches of Mr. Hopkins and of Lord Kelvin have shown this theory to be incorrect. If the interior were mostly fluid, the tides which would be generated in it by the attraction of the moon and the sun would break up any "crust" of the thin nature we have described.

Four main or principal theories have been advanced with respect to the nature of the earth's interior.

1. That it is liquid, with a solid "crust" of no great thickness. This is the theory to which we have just referred.

2. That the central part (called the "nucleus") is solid like the crust, but that the two are separated by a layer of fluid matter.

3. That the earth is solid as a whole, but contains near the surface spaces or cavities filled with fluid.

4. That the earth is solid throughout. This last theory is the idea which has now most supporters.

By modern geologists the term "Crust of the Earth" is restricted to *so much of the solid exterior of the earth as we are able to actually examine.*

At first sight we might seem to be limited in our examination to a very small thickness of the rocks. Railway cuttings, quarries, &c., are at the most less than a hundred feet in vertical depth. Some sea-cliffs rise to the height of several

hundred feet; while the steep narrow valleys (ravines or cañons) of such rivers as the Colorado, are in a few places as much as 6000 feet in depth.

Very few mines go down to a greater depth than 2000 feet. One of the deepest mines in the British Isles is the Ashton Moss Colliery, in Lancashire, the shaft of which goes down to 2850 feet, while the incline from the shaft reaches to a total depth from the surface of 3086 feet.

Bore-holes, usually not more than six or eight inches in diameter, have been made at Battle, near Brighton, to a depth of 1905 feet; South Scarle (Lincolnshire) 2030 ft.; Rampside (Westmoreland) 2180 ft.; and at several points in or near London to depths exceeding 1000 ft. Abroad, the boring at Sperenberg, near Berlin, reached 4172 ft.; and at Homewood, Pennsylvania, 6000 ft.

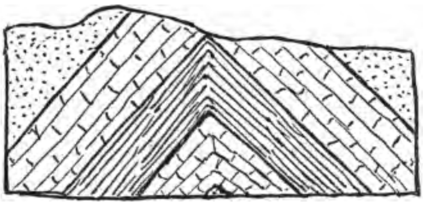


Fig. 18.—Anticlinal arrangement of stratified rocks. The strata have been sharply folded or bent; and the top of the anticline has been much denuded.

But these are all the merest scratchings upon the surface of the colossal globe of our earth. Fortunately, however, the rocks which compose the crust of the earth are not arranged horizontally, one above the other, like the coats of an onion. In most places the strata have been bent and broken: first they have been upheaved and so thrown into great folds, and then the tops of these folds have been worn away by the forces of denudation. The result is, that *we have now forming part of the surface, rocks which were once at a depth of as much as twenty miles.* And so we may say that we know something of the nature and composition of the crust of the earth to as great a depth as *twenty* miles, although in no place are the rocks exposed in natural or artificial sections to a greater vertical depth than a little over *one* mile (see fig. 18).

Nature and Origin of Clay.—Chemically speaking, clay is a hydrated silicate of alumina (containing silica 46, alumina

40, and water 14 per cent). *Kaolin*, which is used for making porcelain, and which is derived from granite by the decomposition of the felspar, is nearly pure clay. We usually, however, apply the term "clay" to any hardened mud which contains enough silicate of alumina to allow it to be moulded and to retain its shape. Ordinary clay always contains a little sand and lime, and is frequently coloured various shades of red or brown by the presence of a little oxide of iron. The particles which compose common clay are extremely small, and were probably deposited on the bottoms of seas at some distance from the shore.

Fire-clay is a fairly pure variety of clay, containing but little water.

Sir A. Geikie defines clay as "a white, brown, red, or bluish substance, which when dry is soft and friable, adheres to the tongue, and, shaken in water, makes it turbid; when moist is plastic, when mixed with much water becomes mud".

Shale.—When clay splits into thin layers along the lines of stratification, it is known as *shale.* Shale, then, is a laminated hardened clay. The miners usually call the shaly rocks they meet with, *bind* or blue-bind; the coal-measure shales, when they contain much carbonaceous matter, look quite black, and are then known as *batt.*

Some shales will split into layers fine as the leaves of a book. These are called *paper-shales.*

Marl.—When clay occurs naturally mixed with a certain amount of lime it is known as marl. Thus marl may be defined as a limy or calcareous clay. When it splits into layers along the lines of deposition, marl is sometimes called "marl-slate", but this is an incorrect use of the word 'slate'.

Sand.—Few substances are better known than the sand which so commonly forms beaches along our coasts, or is seen by the sides of rivers. Ordinary sand is composed largely or altogether of grains of quartz, which are usually more or less rounded by rubbing against each other. These quartz grains come from the disintegration or breaking up of such rocks as granite and sandstone.

Sandstone.—Sandstone is a rock composed of grains of sand held together by some cementing material. The substance which holds the grains together is generally of either a ferruginous, a calcareous, an argillaceous, or a siliceous nature.

In *ferruginous* sandstones the cement is an oxide of iron, which incrusts each grain and gives the rock a yellow or red appearance.

In a *calcareous* sandstone, the cement is carbonate of lime. This can be proved by its effervescence when a little dilute acid is poured on the stone.

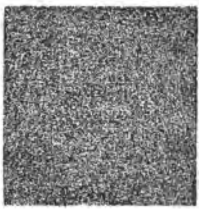


Fig. 19.—Fine-grained Sandstone of even texture.

Argillaceous sandstones contain clay, which can be detected by the earthy smell it gives out when a piece of the sandstone is breathed upon.

Siliceous sandstones are bound together by a paste of hard flinty silica, upon which acids have no effect.

All these cementing materials are well seen when a thin slice of each rock is examined under the microscope.

Varieties of Sandstone.—A sandstone can usually be identified by its rough gritty feel when the hand is passed over it (see fig. 19).

A coarse sandstone, in which the separate grains are so large as to be quite visible, is called *grit.*

Freestone is a kind of sandstone which can be chiselled or cut in any direction, the stone not having a tendency to split one way more than another. It is therefore of much value as a building stone.

Micaceous sandstone contains numerous flakes of mica, whose silvery glitter imparts a pretty appearance to the surfaces of the rock.

Thin-bedded sandstone, which splits into layers each two or three inches thick, is called *flagstone,* because it is largely used for flagging or paving our causeways.

Conglomerate.—A rock composed of rounded pebbles cemented together is called pudding-stone or conglomerate.

Such conglomerates are for the most part old gravel beds or shingle-beaches through which water has slowly circulated. The percolating water contained in solution either oxide of iron, lime, silica, &c., or a mixture of these cementing agents. As it passed between the pebbles the water deposited these substances on and around them, until at last all the spaces or interstices were filled up, and either a ferruginous, a calcareous, or a siliceous conglomerate was produced (see fig. 20).

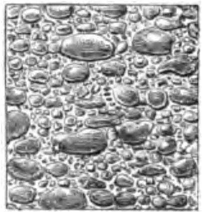


Fig. 20.—Conglomerate, or Pudding-stone.

In some old conglomerates the rounded blocks are of immense size—as much as six feet across—but in an ordinary specimen the included pebbles usually vary from a quarter of an inch to two or three inches in diameter.

Breccia.—When a rock consists of more or less *angular* fragments, embedded in a paste or matrix or cement, it is called a *breccia* and not a conglomerate. Such breccias may have been formed at the bases of cliffs and steep hillsides, and may consist of fragments of rock detached by the agency of frost. Beds of such loose angular fragments may be seen in most hilly districts, especially in Derbyshire and Cumberland, where they are known as "screes". The accumulation or heap of debris at the base of a cliff is called a "talus". Every spring sees a marked addition to these deposits, owing to the action of the frosts of winter in splitting off fragments of the rocks. It is evident that the included stones in a breccia cannot have been carried any distance by running water, or else their angles would have been worn off by rubbing and knocking against each other, and they would have formed a conglomerate instead of a breccia (compare figs. 20 and 21).

Fig. 21.—Breccia; consisting of angular fragments embedded in a matrix.

Limestone.—Perfectly pure limestone is composed entirely of carbonate of lime (the calcium carbonate of the chemists,

$CaCO_3$) and is entirely soluble in dilute hydrochloric acid. Ordinary limestone, however, contains small quantities of clay, sand, oxide of iron, &c.

Limestone varies greatly in its appearance. It is usually a compact rock, but may either be hard and close-grained, or soft and friable. Its usual colours are shades of blue and gray passing into white.

Many limestones are of organic origin, *i.e.* they are mainly or altogether composed of the remains of animals which in former times lived in great numbers in seas or lakes. Most shells, corals, &c., form their hard parts of carbonate of lime, which they secrete from the lime dissolved in the water in which they live. When these creatures die, their hard parts sink down and lie upon the floor of the sea or lake, and if they abound in sufficient numbers they will in time form a bed or layer of rock, which may vary in thickness from a few inches to over a thousand feet.

Chalk is a soft earthy limestone, chiefly composed of the microscopic shells of the extremely small animals called foraminifera. These creatures live in countless numbers in the North Atlantic (and other seas) at the present day. As they die, their tiny shells fall to the ocean floor and there form a white ooze or mud (in which the Anglo-American telegraph cables safely lie) which, if hardened, consolidated, and upheaved so as to form land, would much resemble chalk. We think, therefore, that the chalk which forms the white cliffs of our south-eastern coast, and which extends as low rounded hills from Wiltshire through the eastern counties to Yorkshire, was formed in the same way as this Atlantic 'ooze'. The main proof of this origin of chalk is the appearance of a thin slice of the rock, or of the particles of the rock when it is crushed and well washed in water; under the microscope the tiny shells of the foraminifera are then plainly to be seen.

Coral-rock is a limestone formed by the continual growth, one upon and above the other, of the reef-building coral polyp. Not only are coral reefs now to be seen in course of formation

in tropical seas, but old coral reefs can be found in almost every country: many beds of limestone formed in this way can be seen in different parts of England.

Crinoidal or Encrinital Limestone forms much of the "Mountain Limestone" of which the line of hills is composed that ends in the Peak of Derbyshire, and which has been called "the backbone of England". The rock is usually of a grayish compact appearance; but at the surface, where it has long been exposed to the weather, it is seen to be almost entirely composed of the rings or joints of the plant-like marine animals called *encrinites* or "sea-lilies" (see fig. 95).

Chemically-formed Limestones.—Although most limestones are of organic origin, yet some appear to have been chemically produced by the simple deposition of carbonate of lime either from the water of shallow seas, or from springs. Limestone which is found in detached rounded flattened lumps or *nodules*, is usually of chemical origin. The *hydraulic limestone* of Lyme Regis (Dorset) and of Barrow-on-Soar (Leicestershire) is of this nature. It contains an admixture of silica and of clay, and this gives it the valuable property of "setting" or hardening under water. For this reason it is much used in building piers and harbour walls, &c.

Travertine, or calcareous tufa, is the name given to deposits of limestone, or rather of carbonate of lime, made by springs. The water of such springs incrusts objects placed in it with a stony layer of carbonate of lime; hence it is commonly (but erroneously) said to *petrify* them. The warm springs at Matlock (Derbyshire) are of this nature.

Stalactites.—When water charged with carbonate of lime issues from the roof of a cavern, each drop leaves behind a small quantity of the mineral. In time this forms a long pendent mass, which may ultimately lengthen until it touches the floor. To such finger-like hanging masses the name of *stalactites* is applied. Caverns lined with stalactites have a very beautiful appearance when lighted up. They are common in limestone rocks, as in Derbyshire, Caldy Island (near Tenby), the Mammoth Cave of Kentucky, &c. (see fig. 22).

Stalagmite.—The water which drips from the roof of a limestone cavern to the floor leaves behind still more of its carbonate of lime as it runs over the floor, forming there a crystalline incrustation called stalagmite. In Kent's Cave, near Torquay, several layers of such stalagmite form the floor of the cave; and when broken up the stalagmite has been found to contain the bones of animals which lived in that cave in olden times, together with the weapons and tools of prehistoric man, by whom such caves were also used as dwelling-places.

Fig. 22.—Cave in Limestone Rocks in the Island of Crete, showing Stalactites above and Stalagmite below.

Loess. — In Northern China and Siberia wide-spreading deposits of fine friable yellow mud occur, containing nothing but land-shells and a few bones of terrestrial animals. These deposits have been compared to the somewhat similar river deposits of the Rhine; but more probably they were formed by the action of the wind, for at the present time vast quantities of dust are brought annually by winds and fall upon the plains of Central Asia. After it has once settled down, this dust becomes consolidated by the action of rain, and is subsequently added to by the mud deposited during the flooding of the large rivers.

This loess is generally quite unstratified, consisting of a yellowish limy clay having in some cases a thickness of 2000 feet. Where it has been cut through by the action of rivers it forms high cliffs, which extend on either side of the river-valleys for great distances. In Turkestan, however, the loess is more or less stratified, and varies in composition; moreover it is occasionally intercalated with conglomerates, showing that here running water must have to a great extent assisted in the laying down of the deposit.

Lava.—Lava is a general name applied to all rocks which have issued, in a molten state, from the craters of volcanoes. The lava comes up from the interior of the earth (from an unknown but probably not very great depth) through a vent or pipe; it fills the crater and then overflows at the lowest point of the crater rim (sometimes it breaks through one side of the crater), and then flows down the side of the volcano like a stream of liquid fire, destroying every living thing

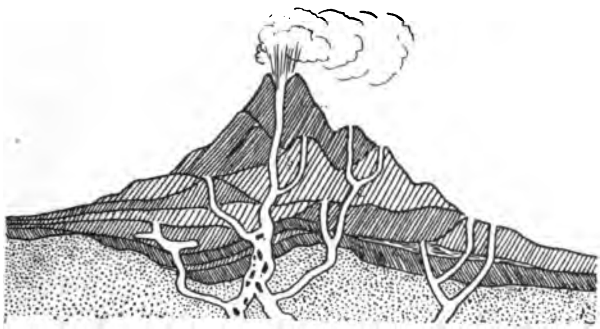


Fig. 23.—Section of an Active Volcano showing several pipes or vents, and also the beds of lava and ashes which have issued from these pipes.

which it meets, and sometimes overwhelming villages and houses.

As the lavas from different volcanoes, or even that which issues at different times from the same volcano, may vary greatly in chemical composition, it will vary correspondingly in its properties. Sometimes the lava is very viscous, in which case it can flow to little or no distance from the parent crater. A good example of this is the old lava (called *domite*) of Auvergne in Central France: this still lies in and upon the vent from which it issued. As an example of the contrary we may name the lava which issued from the crater of Skaptar Jökull (Iceland) in 1783. It flowed to a distance of 50 miles, and the sheet of liquid matter reached in some places a width of 15 miles, while in certain narrow valleys through which it flowed its depth exceeded 500 feet. There can be no disput-

ing these facts, for there the lava stream lies to-day cold and black, waiting inspection (see fig. 23).

When the lava issues from the crater it usually contains much gaseous and vaporous matter, especially steam. During its flow this gaseous matter gradually rises through the lava and escapes from its surface into the air, leaving the rock more or less porous. The upper surface of a lava stream is therefore often extremely rough, slaggy, and porous, while sometimes it is 'ropy'. Very light frothy lava is called *pumice*. When the lava is cooled *quickly*, as by contact with cold rocks or with water, it forms a black glassy rock known as volcanic glass or *obsidian*.

Volcanic Ashes.—During a violent volcanic eruption immense quantities of matter are thrown out of the crater right up into the air—sometimes to the height of several miles—and most of this falls upon the surrounding country in the form of ashes of varying degrees of fineness. At the close of an eruption the lava in the crater and neck cools down and solidifies. Then when a fresh eruption takes place this plug of lava is broken up into small pieces and ejected straight upward, as it might be from a vertical cannon. Also when an eruption is in progress, and the lava is flowing, new outbursts of steam continually occur, and these carry a portion of the molten rock high into the air, where, however, it soon cools, and falls to the ground in rounded masses known as *volcanic bombs*.

The direction in which the ashes fall during a volcanic eruption will depend chiefly upon the wind. If the air should be still, the volcanic ash will fall evenly around, and much of it back again into the crater. But if, say, a strong southerly wind be blowing, then nearly all the ash will fall to the north of the volcano, and *vice versa*. These enormous showers of falling stones, cinders, &c., always hot, and generally containing noxious gases, may do much damage in the neighbouring regions. As they are often accompanied by torrents of rain, much of the ash is at once converted into mud, and this liquid mud fills, surrounds, and flows over everything that comes in

its way. It was thus that the towns of Herculaneum and Pompeii were destroyed by the remarkable eruption of Vesuvius which occurred A.D. 79.

Sometimes the fragments ejected from an active volcano are of immense size; for example, a volcanic block weighing 200 tons, ejected from Cotopaxi, was found at a distance of nine miles from the volcano. The finer dust is often carried by the wind to a distance of several hundred miles from the parent cone.

The larger cinders and ashes ejected from a volcanic cone are known as *scoriæ*—they are porous in structure and rough

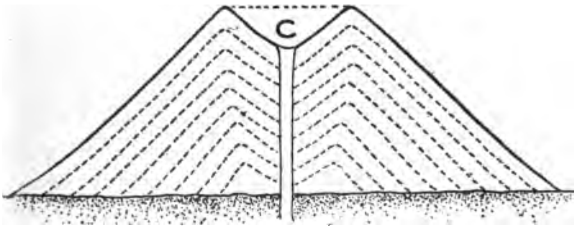


Fig. 24.—Cinder Cone: C is the crater, beneath which is the vertical pipe or vent.

to the feel—while the smaller particles are called *lapilli.* Some small cones are altogether composed of ejected ashes, and these are known as "cinder cones" (see fig. 24).

So great is the quantity of matter ejected from the larger volcanoes, that in the course of centuries extensive layers of ash of all kinds are formed for miles around the volcano, to the thickness of hundreds of feet, and between the ash-beds layers of lava often occur. When, in the course of time, these layers of volcanic ash become hardened and consolidated, they form rocks known as *tuffs.*

Volcanoes have been at work from the earliest periods of the earth's history, and at many places in the British Isles there are rocks—usually rough, dark, and gritty in nature—which can be proved to be nothing but old lavas and ashes ejected from the active volcanoes which formerly existed there. Volcanic rocks very seldom contain any fossils.

CHAPTER VII.

Mode of Arrangement of Stratified Rocks.

What is Stratification?—By stratification we mean the arrangement of matter in the earth's crust in regular beds or layers. Since by far the greater part of the rocks which form the crust of the earth consists of particles which sank slowly to the bottoms of old seas and lakes, we should expect to find these rocks looking like distinct sheets or layers of material, and resting one upon the other. To any single definite bed of rock—such as a layer of sandstone, of limestone, &c. — the name *stratum* is applied, a word derived from the Latin, and meaning something which is spread or strewed out. The plural of this word *stratum* is *strata*, and we use the latter term when we speak of more rock-beds than one. Thus the *stratified* rocks are those which are arranged in layers or strata (fig. 25).

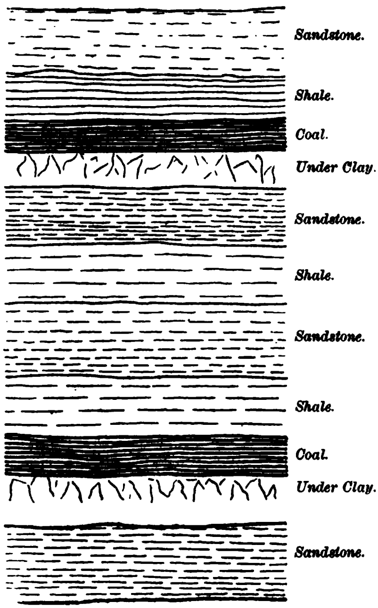


Fig. 25.—Strata showing Seams of Coal; between which come beds of Sandstone, Shale, and Clay.

Laminæ.—Taking up any finely stratified rock—as a piece of shale—we see that it can usually be split into thin layers, sometimes as thin as sheets of paper. Such rocks are said to be *laminated*, and the thin layers are called *laminæ*.

Fossils occur in Stratified Rocks.—In splitting up a piece of rock in the way we have described we may chance to

come across some fossil—the remains of some animal or plant. The creature whose traces we thus see in "the book of Nature" must, in all probability, have lived and died during the formation of the particular stratum in which its remains are now found. The commonest fossils are those of sea-shells. These animals lived in the sea at the time—however remote—when the mud which formed the particular piece of shale we are studying was being deposited on the sea-bottom. The creature died, and its shell sank to the bottom and soon became embedded in the mud. Its soft or fleshy parts decayed away and were replaced by mud; but its hard shell, composed of carbonate of lime, has remained unaltered.

Let us follow some one particular bed or stratum of shale as far as possible. It may be only a few inches in thickness, or it may be hundreds of feet. Perhaps we can trace it across country for many miles in quarries, pits, cuttings, &c. From it we may succeed in getting a great many fossils. Some of these will be exactly alike, they will be of the *same species*; and some of these species will be common and others rare. Perhaps, altogether, we succeed in securing thousands of individual specimens; but when these come to be examined we find that many of them are exactly alike, so that we have only about one hundred distinct forms or *species*. Then we may be pretty sure that wherever in England, or in Europe, or indeed we might say in the world, we find a stratum of rock containing most, or even many, of these particular species of fossils, that rock was formed at or about the same time, and is therefore of the same geological age as our original stratum of shale.

That was the great discovery made by William Smith—the identification of strata by their organic or fossil remains.

Geological Use of the term "Formation".—By the term "formation" the geologist means a group of strata which have certain characters in common, and which therefore must have been *formed* or deposited at or about the same geological epoch. Thus all the stratified rocks are arranged in fifteen or twenty great groups or formations. The task of classifying

the strata in this way—grouping together those beds which are alike, and drawing lines of demarcation to show where one formation ends and another begins—is one of the great objects of geology. In this work the geologist finds the *fossils* contained in the rocks to be of the greatest possible service.

In the latest-formed rocks—those which have accumulated during, say, the last ten or twenty thousand years—the geologist finds the remains of many creatures—many fossils; but these can be matched *exactly* with animals or plants *still living.* That is, they all belong to what we call recent species. There are certainly a few exceptions to this, a few species have died out (chiefly owing to their destruction by man) in recent times —but they only "prove the rule".

In rather older rocks, which were formed, perhaps, a quarter of a million years ago, *a few* of the fossils are not precisely like anything which now lives. These are *extinct species.* Examining older and still older rocks, we find the traces of life which they contain to differ more and more from the animals and plants which to-day inhabit the earth, until in the oldest rocks many of the fossil forms are indeed most curious and remarkable (see figs. 26 and 27).

Each bed, each stratum of rock, has usually a few fossils which are peculiar to itself, while the rest of its fossils are found also in the beds which come immediately above and below it. Taking a group of strata which contains the *same general assemblage* of fossils, we can say—"all these rocks must have been deposited during one and the same era of the earth's history, whether it be one or twenty millions of years back". The separate members or layers of such groups of strata also usually lie one above the other in *parallel* lines, showing that no important disturbances of the crust of the earth—no great upheavals or depressions—occurred while this particular series of strata (this *formation*) was being deposited.

Take the Old Red Sandstone as an example of a geological *formation.* Throughout its thickness of some thousands of feet of reddish sandstones the strata which compose it (*a*) lie parallel to one another, and (*b*) contain the same remarkable

group of fossil fishes which so surprised the geological world when Hugh Miller first laid them bare with his hammer.

The NEW RED SANDSTONE is another geological *formation* also distinguished by the generally red and sandy nature of the strata which compose it. How then can geologists distinguish the one from the other? Chiefly by the fact that the fossils of the two formations are totally dissimilar. The "Old Red" Sandstone was formed probably millions of years before the "New Red", and during that long interval of time every species of animal and every species of plant which inhabited the earth in the older time had died out, or at least become so changed as to be very different in appearance. To each of these two "sets of strata" we therefore, in geology, give the name of a **formation** (see figs. 26 and 27).

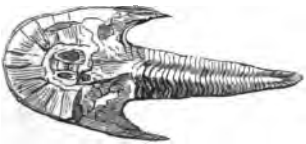


Fig. 26.—Cephalaspis Lyellii; a fossil fish characteristic of the Old Red Sandstone.

Fig. 27.—Labyrinthodon Salamandroides (restored), an amphibian characteristic of the New Red Sandstone.—Owen.

The Formations Grouped.—Although very few *species* of fossils pass from one formation to another, yet many *genera* do so pass, and hence several formations may be shown to have some relationship the one with the other, and to be allied to a certain extent.

Geologists have accordingly arranged the fifteen or twenty *formations* of which we have spoken into four great groups, and in making this division they have been guided mainly by the evidence offered by the *life*—the fossils—of each group.

The Eozoic (or Pre-Cambrian) Series.—Under this head we include a great thickness of so-called "Primitive" or "Bottom Rocks", of which we as yet know very little. Fossils are only doubtfully present in these very ancient rocks, but

the work of the next few years will certainly cause them to reveal many of their secrets.

The Palæozoic Series.—The six geological formations which lie between the Eozoic series below and the Mesozoic series above, are united into a great series or group called PALÆOZOIC (from the Greek *palaios*, ancient, and *zōē*, life). The great majority of the fossils found in this group differ *widely* and materially from the animals and plants which now inhabit the earth.

The Mesozoic Series.—To the next group of four formations the name of MESOZOIC (Greek, *mesos*, middle, and *zōē*, life) is applied. The fossils in these 'middle rocks' belonged to forms some of which were not unlike creatures now living, although on the whole there is still a great difference.

The Cainozoic Series.—Lastly, the six latest-formed or newest formations are united into a group called CAINOZOIC (from the Greek *cainos*, recent, and *zōē*, life). Even in the lowest (oldest) rocks of this Cainozoic series a few of the fossils cannot be distinguished from certain species now living; while in the uppermost of the Cainozoic strata *all* the fossils are of still living or recent forms.

Arrangement of the Stratified Rocks in the Crust of the Earth.—The total thickness of the stratified rocks exceeds 100,000 feet. Although no mine, cutting, or valley exposes in one section the tenth of this great thickness, yet the whole of the stratified rocks can be readily examined at some point or other on the surface of the earth. The reason of this is that the strata do not, as a rule, lie regularly and horizontally one above the other, like the coats of an onion. Owing to the great, though slow, movements of the crust of the earth, which have been in progress since the earliest times, the strata have here been upheaved and there depressed, being thus thrown into long folds and curves. Where the rocks have been most upheaved—as in mountain chains, &c.—there they have been most exposed to the action of the weather, by which many thousands of feet of rock have often been worn away. The result is, that in mountain regions we usually find

the *oldest* rocks forming the **highest** elevations; while the *newer*, later-formed strata which once covered these old rocks over, must now be sought for in the surrounding **plains** (fig. 28).

It is true that in some parts of the world, as in the old kingdom of Perm, in Russia, the land has been elevated so steadily and evenly that the whole surface of the country is a plain formed by a single horizontal stratum of rock. But this is exceptional. As a rule the land is formed of the bared or denuded *edges* of the strata, and not of their original surfaces. This is the reason why a geological map of England shows a

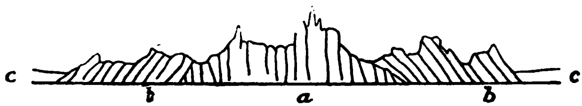


Fig. 28.—Section across a Mountain Chain, showing two periods of upheaval: *a*, the oldest and first elevated rocks; *b*, *b'*, later-formed strata, showing a second elevation; *c*, *c*, third and still newer group of strata.

number of coloured bands running across the country from south-west to north-east. Each colour marks the edge of a certain formation which there occupies, and, indeed, forms the surface or ground.

Outcrop of Strata.—Consider any individual stratum, such as a seam or bed of coal in a mine. It *may* be horizontal, but in most cases it will be found to be inclined at a greater or less angle. If we follow it in one direction we shall there find it going deeper and deeper into the crust of the earth; but if we now take the *opposite* direction we shall find the coal-seam approaching the surface, and at last *cropping out* to the day-light. The portion of the surface of the country occupied by this particular bed is called its *outcrop*. If the stratum is vertical, the width of the outcrop will be the same as the thickness of the stratum; but if, as is usually the case, the stratum crops out at a low angle, the width of the outcrop will be many times greater than the thickness of the stratum. In a level country the outcrop runs in a straight line; but every hill and every valley change its direction; so that usually it forms a wavy band of varying width.

Dip of Strata.—Strata which lie horizontally have no dip;

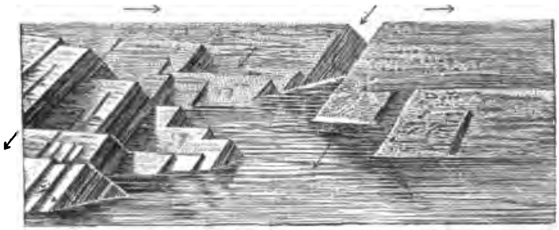


Fig. 29.—Dip and Strike. The horizontal arrows indicate the Strike; those pointing towards the left-hand corner show the direction of the Dip.

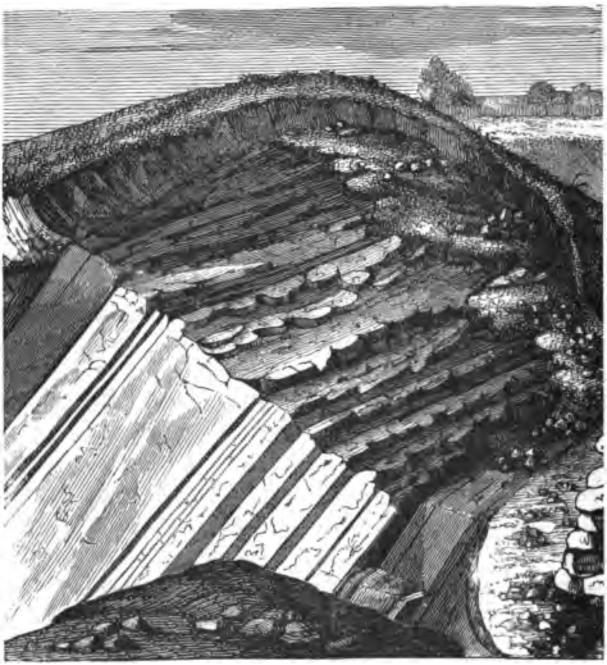


Fig. 30.—Quarry from which the surface soil has been removed. The strata Dip about 45°, while their Strike is shown on the surface where the rocks have been bared.

while those which "stand on their head", or are vertical, are said to *dip* or incline 90 degrees. Between these two extremes

the beds of rock may *dip* any number of degrees—as 10°, 20°, 30°, &c. Dip is, in fact, the inclination which any stratum makes from the horizontal line, and its amount is measured by the angle included between the plane of its surface and the plane of the horizon (figs. 29 and 30).

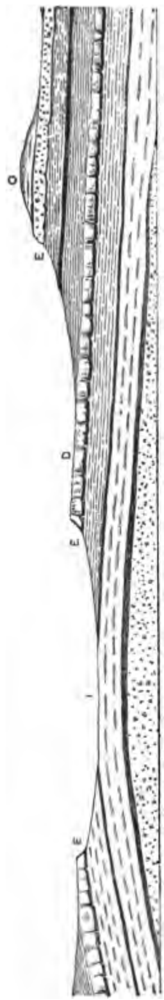


Fig. 31.—Strata bent into an anticlinal curve or fold. The abrupt cliffs at E, E, E are called Escarpments. An Inlier is shown at I, and an Outlier at O.

As a rule, instances of extreme dip—70 or 80 degrees—are most common in *old* rocks. The more newly-formed strata—those of Mesozoic or of Cainozoic age for example—usually dip at low angles, generally not exceeding 5 or 6 degrees.

Taking the strata which compose England as a whole, their dip is to the south-east. We must always note the *direction* of the dip as well as its amount. The angle of dip can be measured, roughly, by the eye. To measure it more exactly, an instrument called a clinometer is employed.

Strike.—The term "strike" is used, geologically, to indicate the direction of any stratum at the surface *measured at right angles to the dip.* Thus, if the strata dip to the south, the line of strike of those beds must be east and west. If the strata dip to the south-east, as is generally the case in England, they will *strike* from south-west to north-east.

Very often 'strike' is mistakenly said to be exactly the same as 'outcrop'. This is quite a mistake. It is true that the two will coincide where the ground is level (and also where the strata are *vertical*); but where hills and valleys are found, the outcrop is continually changing its direction to follow the curvature of the

surface, while all the time the *strike* may, and probably will, remain unaltered (see fig. 30).

Lie of Strata.—Any bed of stratified rock must lie either (1) horizontally; (2) vertically; or (3) be inclined at some angle to the horizon (see fig. 31).

Strata which lie *horizontally* have neither strike nor dip.

Vertical strata owe their position to some considerable motion of that part of the earth-crust in which they occur, by which one part or end of each stratum has been raised and the other depressed. Although we call the motion "considerable" yet

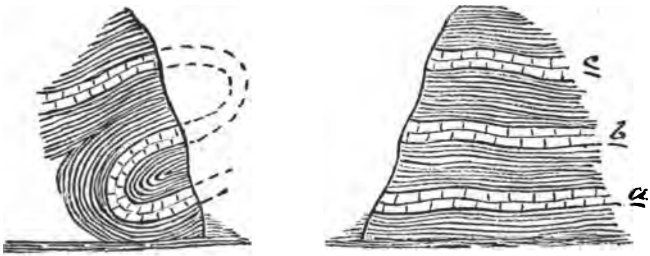


Fig. 32.—Side and Front of Cliff. In the front view the strata appear to be horizontal, and to contain three beds of limestone, *a*, *b*, and *c*. The side view shows that the strata are in reality folded and contorted, and that there is only one bed of limestone. The dotted lines represent portions of the limestone bed which have been denuded.

it need not have been rapid. We have, indeed, every reason to believe that such earth-movements take place very slowly; although in the long run they produce such striking and well-marked effects.

We assume that all the strata which we now see to be *inclined* at various angles—perhaps even standing vertically—were originally deposited in horizontal layers on the floors of seas which formerly existed where these rocks now stand.

It most commonly happens that strata are *inclined* in some direction or another. If we go among the old rocks which form much of North Wales, of the Highlands of Scotland, of the Swiss Alps, &c., we shall see plenty of sections where the rocks even stand on end, or are *vertical.*

But before deciding as to the exact amount of inclination or dip of the strata as seen in any quarry, or cliff, or railway-

cutting, &c., we must make sure that *we see the beds at right angles to the strike.* If the section happens to have been made parallel to the strike, the strata will *appear* to be horizontal, although in reality they may have a considerable dip (fig. 32).

Curved Strata.—Most natural sections or exposures of beds of rock—as quarries, &c.—only show us a few yards of the strata either in length or in depth; and for this limited space the strata may, and generally do, appear as *straight* bands, usually *inclined* or dipping in some direction or other. But if we are able to follow the beds for any considerable

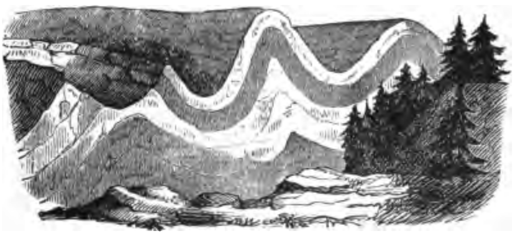


Fig. 33.—Section across the Jura Mountains, showing three Anticlines and two Synclines. The crest of one Anticline has suffered denudation.

distance, we are pretty certain to find that they are really arranged in long folds or *curves.*

When the curvature is such that the strata dip *away from a central line* or axis, they are said to form an *anticline*, or saddle-back; and the line from which they dip is called an anticlinal axis.

On the other hand, when the beds dip *towards* a central axis, they form a *syncline* or trough, and the central line towards which they slope or dip is called *a synclinal axis.*

We might expect to find anticlinal axes running along the crests of hills, and synclinal axes along valleys. Certainly this is sometimes the case, as in the Jura Mountains of Switzerland; but more frequently it is just the opposite.

The fact is, that in an anticlinal axis, the beds having been bent over and stretched, the rocks along the summit of the fold have been cracked, fissured, and opened; so that the

agents of denudation—rain, frost, ice, &c.—are able to do their work very rapidly. The rocks are thus rapidly broken down, and in course of time the ridge is converted into a valley (see fig. 33).

Fig. 34.—Contorted Strata. All the bands of rock shown were originally horizontal and continuous.

In a synclinal axis the opposite is the case. The particles of the rocks are there *pressed together*, and this enables them to better resist the action of the weather. The result is, that when in course of time the surrounding strata become worn away or denuded, these synclinal axes often remain and form hills.

Contorted Strata.—During the movements of the earth-crust which have taken place in past ages, it has often happened that a lateral or side pressure has been exerted upon the rocks. Where, for example, in any volcanic district the rocks became greatly heated, they would expand, and all the strata surrounding them would feel the effect.

When the strata are bent into violent curves or folds they are said to be *contorted*. Such contortions of the rocks occur most frequently among the *older* strata and in mountainous regions (see fig. 34).

Inverted Strata.—Where the lateral (side) pressure has been great and long-continued it may happen that the strata have been bent right over each other over and over again, just as a housewife folds the dough in making it into paste. Examples of this are common in the Swiss Alps; and the

strata are then said to be *inverted, i.e.* turned upside down (see fig. 35).

In the Scottish Highlands it has lately been shown that in a similar way portions of the folded strata have actually been detached or torn off from the main mass and then pushed over the other rocks from east to west for many miles. The lines along which such a motion or sliding of the rocks takes place are known as *thrust-planes.*

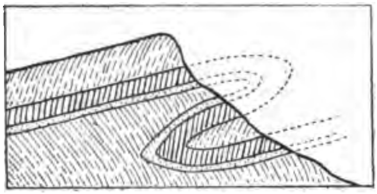


Fig. 35.—Inverted Strata; the dotted lines indicate the manner in which the folding and inversion have taken place, and represent portions of the strata which have since been removed by denudation.

In some sections—as in the old rocks which form the South Stacks, near Holyhead—not only are the strata corrugated and crumpled on a large scale, but the particles of each individual bed show the same thing on a smaller scale. When fossils occur in such rocks they are usually so drawn out and changed in shape as to be almost or quite unrecognizable.

A Geological Basin.—If the strata everywhere incline towards a central spot or point, we compare the arrangement to

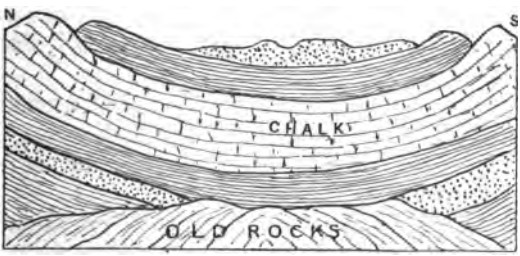


Fig. 36.—Diagrammatic Section from North to South across the London Basin. A ridge of old (palæozoic) rocks occurs at a depth of about 1000 feet, and the newer strata above this ridge lie in a gentle hollow or syncline.

a basin. Thus in England, among the newer strata, we distinguish the Hampshire basin from the London basin: and many—indeed most—of our coal-fields also have their strata arranged in this basin-shaped manner. In each basin the rocks must,

when viewed as a whole, have a synclinal order or arrangement. We may compare the different layers of rocks to a "nest" or series of basins placed one within the other (fig. 36).

Conformable Stratification.—To "conform" is to agree with; and conformable strata are those which agree with each other in either their dip or their horizontality, being always parallel to one another, bed to bed (see fig. 37).

Where the strata are both parallel to each other and composed of the same materials, as sandstone, shale, slate, &c., the *probability* is that they were deposited, layer upon layer, at the bottom of the same sea or lake, and during the same geological epoch.

Fig. 37.—Conformable Strata. All the rock-beds are parallel—and therefore conformable—to one another, although on the left of the diagram they are contorted.

If we also succeed in finding similar species of fossils in all the layers of rock, from the lowest to the highest; or even if the species change very gradually, some dying out while new forms come in—certain of the species, however, persisting throughout—the probability that the set of strata belong to one and the same geological formation is changed to a practical certainty.

Ordinarily, throughout any one geological formation the strata are fairly parallel or *conformable* to each other. This is, indeed, one reason which induces us to class any set or group of rocks together as a single formation.

Unconformable Stratification.—When the stratified rocks of a country are carefully examined, we find that although the individual beds of rock which compose any one formation usually lie parallel to one another, yet when we examine the *junction* between one formation and another formation there will generally be seen a want of parallelism between the strata of the two great divisions (see fig. 38).

An extreme case, but one which is not uncommon, is where the strata composing the older formation are seen to be vertical

(dip = 90°), while another set of newer rocks lie horizontally (dip = 0°) on the upturned edges of the former. The strata are then said to be *highly unconformable* to each other (see fig. 39). This unconformity indicates a lapse of time—probably a very great interval—between the deposition of the two sets of strata. The older rocks must, by movements of the earth-crust, have been disturbed, consolidated, hardened, and upheaved, before the newer, later-formed strata were deposited on their upturned edges.

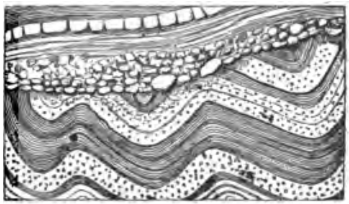


Fig. 38.—Unconformable Strata. The lower set of beds were disturbed and bent into folds before those above them were deposited. A conglomerate band is seen at the junction.

At such an unconformable junction between two formations it is very common, too, to find a bed of conglomerate, composed of pebbles of the older rocks. This would show that the lower strata had been raised up to or above the sea-level, and had been partly broken up and denuded by the agencies of the sea and the weather before the newer beds were deposited upon their upturned edges (fig. 38).

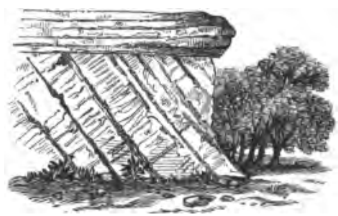


Fig. 39.—Section at Frome (Somersetshire) showing Unconformable Stratification. Horizontal Oolite Strata resting on upturned edges of Mountain Limestone.

In some cases, in greatly disturbed regions, when the rocks are much contorted, it is possible to tell which is the older of two rock-beds, by finding fragments of it (as pebbles, &c.) in the newer and later-formed stratum.

From extreme cases of unconformable stratification like that mentioned above, we pass to cases where—the difference of dip between the two beds being only two or three degrees—it is not possible to detect the unconformity in a single small section, as a quarry, &c. But even in these examples the effect

becomes very evident when a larger area is examined. As a general rule, of course, the greater the unconformity the greater is the period of time there unrepresented by any deposits.

It is possible, of course, to have unconformity between two formations which, in the sections examined, are strictly parallel to each other. The older beds must there have been upheaved and again depressed with great evenness. But even in such a case the unconformity is generally easy to detect by the fact of the surface of the older rock being worn into hollows, which are filled up by the newer strata; and by the bed of conglomerate which almost invariably exists at such a junction.

Diagonal or Cross Stratification.—In certain rocks, more especially in sandstones, it is common to see that while the main beds of rock (each 4 or 5 feet in thickness, perhaps) are parallel to one another, the laminæ of each bed slope at an angle. And those of a main bed above may slope or incline in quite a contrary direction to those of a main bed below. Such an appearance must be carefully distinguished from *unconformable* stratification, with which inexperienced workers are apt to confound it. It is a case of diagonal or cross-stratification, or, as it is more commonly called, *false-bedding* or *current-bedding* (see fig. 14).

This false-bedding must have been especially produced during the deposition of sediment (sand, &c.) in shallow seas traversed by swift currents which flowed now from one direction, now from another. Under such conditions sand-banks are formed, and the sand is swept along the top of the bank until it rolls over at the end, where it forms layer after layer, all parallel to one another, but inclined to the horizontal top of the sand-bank at an angle of (usually) about 45°. Then, from some cause or other, the current shifts its direction, and another bank of sand is deposited on top of the first one, but with its layers or laminæ inclined, perhaps, in a different direction.

In trying to ascertain the *real* dip and the *real* conformity of false-bedded rocks, we must look at the *main* lines of bedding only, and even then we may be deceived if we confine our observations solely to any one point or section.

Occasional Absence of Strata.—Where a great unconformity occurs, it frequently happens that one or more of the geological formations is there *unrepresented*. For example, in the west of England (Somerset, &c.) we often see Liassic or Oolitic beds resting on the edges of Carboniferous strata (see fig. 39). Where the series of stratified rocks is complete, both the Permian and the Triassic formations lie between the Carboniferous formation and the Lias, but in the sections just cited they are missing. Why is this? Either the Carboniferous rocks in the west of England were upheaved and remained as dry land while Permian and Triassic strata were being deposited elsewhere; or, supposing these two formations to have been laid down in these parts of Somerset, &c., they were removed by the agents of denudation before the Liassic strata were deposited. In either case the unconformity between the Carboniferous and the Liassic or the Oolitic strata is evidence—which other considerations prove to be perfectly correct—of a great interval of time having elapsed in this district between the deposition of these two sets of strata.

The succession of stratified rocks may be compared to the succession of the letters in the alphabet, from A to Z; A standing for the newest, latest-formed strata, and Z for the oldest.

Then this succession is uniform and invariable, A being always found *above* B, and B above C, and so on.[1] But in repeating the alphabet we may *omit* some of the letters; and so, in any district, certain strata may be absent or wanting. Thus bed A may repose upon bed C, or even upon bed Z, all the intervening strata being missing. But the *order of succession* will always be the same: A at the top, B above C, then C above D, and so on, with Z at the bottom.

[1] Except in those rare cases of *inversion* of the strata which we have already alluded to as occurring in the Alps and in certain other districts where the rocks have been greatly disturbed.

CHAPTER VIII.

ARRANGEMENT OF STRATIFIED ROCKS—(*continued*).

Overlap.—When strata are deposited on a surface—as a sea-floor—which is gradually descending and extending, each successive bed will *overlap* or extend beyond the one previously formed (see figs. 15 and 16). All the different layers of the new deposit will be conformable the one to the other, but they will be unconformable to the older rocks which form the sea-floor on which they are laid down. The effect of overlap will be to *increase* this unconformity. We thus have *conformable overlap* between the different layers of the new deposit; and unconformable overlap or *overstep* between these layers and the beds of the older rocks which form the sea-floor.

Outlier.—An 'outlier' is a portion of a stratum which has, by denudation, been separated from the bed with which it was

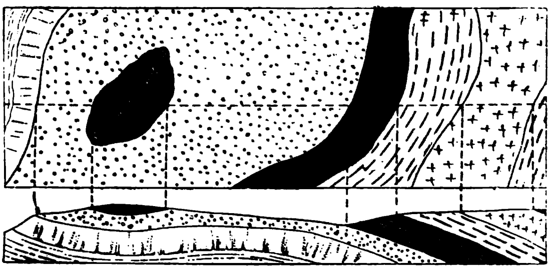


Fig. 40.—Plan and Section of an Outlier. The "plan" shows the strata as they would appear to anyone looking vertically down upon them—as from a balloon. In the "section" we see the arrangement of the different rock-beds as it would be revealed by digging through them a deep trench or cutting, along the horizontal, dotted line.

originally continuous. It is, therefore, now entirely surrounded by older rocks (see fig. 40). Take the geological formation called the Lias as an example. Its main mass or outcrop runs from Dorset, through East Leicestershire, to Yorkshire. But detached patches of Lias occur far to the west of this main mass, as at Whitchurch in Shropshire, and near Carlisle, &c. We therefore believe that the Lias once stretched much further

to the west than it does at present, and that these outlying patches are the sole remnants of a very considerable mass of rock, all the rest of which has been removed by the agents of denudation—rain, rivers, the sea, &c. The individual strata in any outlier most commonly lie in a basin-shaped form; and it is this fact which has enabled such patches to resist denudation better than the rocks which once surrounded them, but which have been washed away.

Inlier.—An 'inlier' is, geologically, exactly the opposite of an 'outlier'. It consists of a *portion* of some stratum ex-

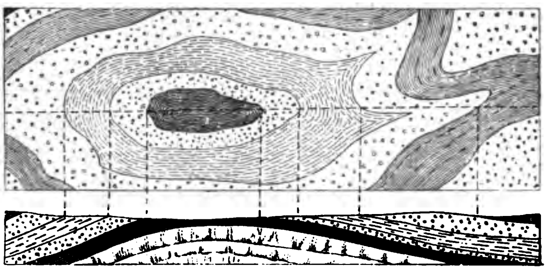


Fig. 41.—Plan and Section of an Inlier.

posed by the removal of the newer strata which once covered it. This frequently results from the beds of rock having been bent into a dome-like shape, and then the top of the dome has been denuded off (see fig. 41). Inliers are also not uncommonly the result of those dislocations of the strata which are known as 'faults'. Charnwood Forest, in Leicestershire, is a good example of an 'inlier'. Is is composed of very ancient Pre-Cambrian slates and volcanic rocks whose main mass occupies portions of the extreme west of Wales and Scotland.

Jointed Structure of Rocks.—Almost all rocks are divided into masses of greater or less size by a series of cracks or *joints* which cross them in two directions—one set very frequently running in the direction of the strike (strike-joints), and the other set in the direction of the dip (dip-joints). By these natural fissures the rock is divided into blocks which allow it to be quarried. The main or master joints in sand-

stone, limestone, and indeed in most hard rocks, are usually very distinct and well marked, and give the rock a 'blocky' appearance in a quarry. But often there are other and finer joints, which do not become evident until the stone is struck by a hammer, when it breaks readily along these hidden joints.

Joint-structure is believed to be mainly due to the *contraction* of rocks when cooling and drying—something similar may be seen in starch and in clay when allowed to dry—but the movements of the earth-crust, causing the strata to be twisted and pressed, have also had something to do with its production, especially in the case of the master-joints.

Fissile and Flaggy Structure.—The term stratum, or bed, is usually applied only to a layer of a certain thickness—say at least an inch, though more commonly much thicker. The top and bottom surfaces of a stratum are called the bedding-planes. It is generally the case that the strata will split more easily along and parallel to the bedding-planes than in any other direction. When they split readily into layers some 2 or 3 inches in thickness, the strata are said to have a 'flaggy' structure; because certain hard sandstones and limestones which split in this way are much used for paving or flagging the side-walks of streets.

Many such rocks will split into thinner layers still when struck on the edge with a hammer; they are then said to possess a *fissile* structure.

It must be remembered that these layers are parallel to the bedding-planes, and therefore parallel also to the lines of deposit or stratification.

It is not difficult to see why most stratified rocks should have this tendency to split into layers. The particles of which they are composed are (as can be seen under the microscope, or sometimes even with the naked eye) more or less flattened. As these particles sank to the bottom of the sea or lake in which the stratum was formed, they settled down upon their flat sides, layer upon layer, all parallel to one another and to the surface upon which they were laid down. Since that time, they have been pressed (by the weight of all the rocks above

them) in a way which would increase their tendency to split along the lines of stratification.

Sandstones composed of well-rounded grains show little of this fissile structure; but in micaceous sandstone the thin glittering spangles of mica impart a certain amount of this kind of fissility to the rock.

On the other hand, in certain beds of shale we get the fissile structure so well developed that the rock will split up into layers as thin as sheets of paper. Such shales are often called "paper-shales"; they occur in the Rhætic Beds and elsewhere. Microscopical examination shows these paper-shales to be composed of extremely small and thin particles, very uniform in size.

Lamination of Rocks.—It must be remembered that the term "fissile" is applied to *all* rocks which split into thin layers, no matter to what cause that splitting is due. Thus shale and slate are both fissile rocks, although their fissility is not due to the same cause.

When a rock has a fissile structure which is owing—as we have explained—to the way in which the *particles* of that rock have been originally deposited on some sea-floor, to the shape of those particles, and to the vertical pressure to which the rock has been subjected owing to the weight of the rocks above it, the rock is said to be *laminated*, or to have a laminated structure; and the separate layers are called laminæ. Shale is perhaps the best example of a laminated rock.

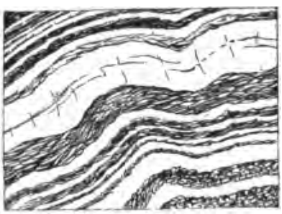


Fig. 42.—Foliated Structure in Rocks.

Foliation of Rocks.—The word 'foliation' is derived from the Latin *folium*, a leaf. The term is a good one, because the different minerals which compose a foliated rock are arranged in a way which reminds us of a bed of fallen leaves (see fig. 42).

Gneiss is a good example of a foliated rock. It is composed of the three minerals quartz, felspar, and mica, arranged—not in regular continuous layers—but in patches or leaves, as it

were, one above the other. Mica-schist, talc-schist, chlorite-schist, &c., have a similar structure. In fact, so common is this foliation in the rocks called schists, that it is often spoken of as a "schistose" structure. Such rocks have a tendency to split along the lines of foliation. As to the cause or causes of foliation we cannot be certain, but it is probably due to the combined action of pressure and a moist heat. In fact, all foliated rocks are more or less *metamorphic*; that is, they are rocks which have undergone great changes since the time of their original formation.

Cleavage of Rocks.—To cleave means to split. Now *wax* seems an unlikely substance to possess the property of splitting; yet by subjecting paraffin wax to *great pressure* Professor Tyndall succeeded in obtaining it in a state in which it would readily split into layers not much thicker than sheets of paper. In geology we apply the term cleavage to the property which causes certain fine-grained rocks to split readily in a direction which may or may not coincide with their lines of stratification, but which is quite independent of it, and is, indeed, usually at a considerable angle to it (see fig. 43).

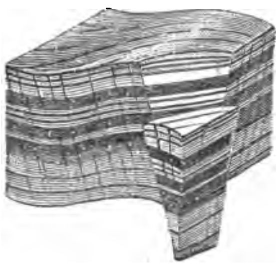


Fig. 43.—Cleavage. The horizontal bands (or "stripe") show the stratification; the fine lines (nearly vertical) indicate the direction in which the rock "cleaves".

Slate is perhaps the best-known example of a cleaved rock. That slate was deposited as clayey mud, which hardened into shale, admits of no dispute. If we could have examined the rock at an early period of its existence we should have found it capable of splitting parallel to its bedding-planes only. But there came a time when this old shale was submitted to immense pressure—generally this was a lateral or side pressure—and its tiny particles were rearranged or flattened out so as to be perpendicular to this new pressure. In the famous slate-quarries of North Wales we can still distinguish the original planes of stratification by means of the changes in the colour

and texture of the successive beds—the *stripe* of the slate, as it is called—but the rock splits or cleaves into roofing-slates at an angle of about 70° to these. Fossils, pebbles, &c., which may be included in cleaved rocks, are usually much drawn out, flattened, and distorted. Although *pressure* has been the chief

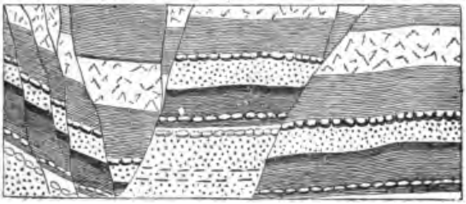


Fig. 44.—Section of Rocks traversed by numerous Faults. All the strata shown were deposited as continuous horizontal beds of sandstone, shale, &c.

agent in producing cleavage, yet heat, assisted by chemical action, has also assisted in the metamorphosis.

When layers of some coarser rock, as sandstone, are interbedded with slate, the cleavage is usually confined to the latter rock.

Faults or Dislocations of Rocks.—A fault or dislocation is a crack or fissure in the strata at any place, on one side of which the beds have almost invariably been either elevated or depressed, so that they are now no longer continuous with the same beds on the other side of the fissure (see fig. 44).

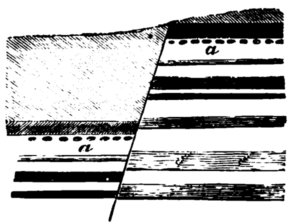


Fig. 45.—Normal Fault. The beds *a*, *a* were once continuous. The fault hades or inclines to the left of the diagram at an angle of over 60°.

Such dislocations of the strata have been produced during the motions of the earth-crust in past ages. As the rocks that now compose the land are for the most part *stratified* rocks that were formed at the bottom of old seas, it is certain that they must have been *elevated* to their present position, while it is equally certain that other strata have been both elevated and depressed. During this process of elevation

and depression of hard rocks, extending over hundreds or thousands of square miles, the strata have broken or given way here and there, and then the rocks on one side of the line of fracture have been parted from those on the other, being either raised to a higher or depressed to a lower level (see fig. 45).

It is evident that the older the rock the more likely it is to be traversed by faults. The strata deposited during the earlier stages of the earth's history have in most cases undergone both elevation and depression many times, while the later-formed strata have less frequently been subjected to such stresses.

Fig. 46.—Mineral Vein or Lode. The original crack or fissure extended from *a* to *a*; but this has been almost filled up by mineral matter deposited simultaneously on each side of the fissure (as at *b*, *b*; *c*, *c*; &c.) by water trickling through it.

Lodes and Veins.—A fissure or crack in the earth-crust which has been filled up with a mineral or minerals is called a lode or mineral vein. As a rule the lodes cross the bedding-planes at a considerable angle, but sometimes they are nearly or quite parallel to the lines of stratification, in which case it requires care to distinguish them from interstratified beds. A lode may be of any breadth, from a fraction of an inch to many yards, and the larger lodes can often be followed for many miles across a country. The same fissure is often both a lode and a fault (see fig. 46).

In mining districts it is common to restrict the term "lode" to fissures which contain metallic minerals, or at all events something which makes them worth working. If the fissure is filled with some substance which is of no value to the miner he then calls it a *vein*.

The commonest veins are those threads or strings of calcite and of quartz which are so common in nearly all rocks. White veins of calcite are not uncommon in coal. It is from the quartz veins in palæozoic rocks that practically the whole of the gold we use has been derived. For although gold-dust is also found in river-gravels, muds, &c., yet all this has probably come from the breaking-up or denudation of old rocks containing auriferous lodes of quartz.

The tin and copper of Cornwall, the lead of Derbyshire, and, in fact, these and similar metallic minerals in most countries are obtained from lodes which occur in old rocks.

As to how the minerals got into the fissures? They were originally contained *in solution* in the warm or hot water which traverses all rocks, and were slowly deposited on the sides of the fissures as the water trickled along. Some minerals may have been condensed from vapours which similarly traversed the fissures.

Relation of Mineral Veins to the Rocks which they traverse.—In all cases mineral veins are posterior in date to the rocks which inclose them; and it is also a general fact that a relation exists between the composition of the minerals forming the vein and the nature of the rock in which the vein occurs. It has further been shown that the rocks in the immediate neighbourhood of the vein are affected by the minerals which make up the mineral vein itself. There seems, in fact, to be a kind of reciprocal action.

Metalliferous and mineral veins occur in every variety of rock—in limestones, shales, and slates; in granites, in basalts, and in metamorphic rocks. Except in particular districts, the existence of mineral veins seems to be quite independent of the chemical composition of the surrounding rocks.

The mineral known as iron-pyrites occurs in limestones and chalk; in slates, shales, and clay; and in basalt. Copper-pyrites is more restricted, occurring in veins in limestone, sandstone, and shale; in mica-schist, and in granite. In one and the same kind of rock (granite, for example) we may have veins of tin, silver, lead, and copper.

The character and composition of the included minerals frequently changes as the same vein traverses rocks of different composition. Thus in Cornwall many veins rich in copper ores pass through clay-slate and enter granite; at the junction of the two rocks the veins are usually very productive in copper, but as the veins are followed into the granite the copper ore in the veins becomes less and less in quantity, and is frequently altogether replaced by ores of tin.

In the north of England veins of galena frequently pass through carboniferous limestones and shales. It is a fact well

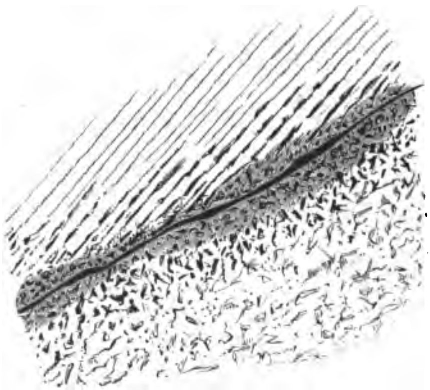


Fig 47.—"Stockworks ': the rocks are traversed by a narrow vein, and the shading on each side of this vein represents the portions of the rocks which are rich in ore.

known to the miners that those parts of the veins which traverse the limestones are far more productive than those which are surrounded by shales. The contents of a vein sometimes vary with the depth; thus in the veins in the Cumberland slates the upper parts invariably contain lead ores, while in the deeper or lower parts copper minerals abound.

The walls of rock which bound the veins on either side are frequently cracked and indurated, although in clay-slate (as in Cornwall) the walls are softened, and even converted into clay. In some cases the rocks on either side of the vein are greatly decomposed, especially if they contain much felspar. The mineral matter filling the vein is not always confined to the

vein alone, but is frequently disseminated throughout the adjoining rock for some distance on either side. This is especially the case with the tin and copper ores contained in veins which traverse granite, the granite rock near the vein being sometimes even richer in mineral matter than the vein which passes through it. Such impregnated masses of rock are termed 'Stockworks', those at Bodmin, in Cornwall, which occur in granite, clay-slate, and elvan, being well known (see fig. 47.)

Dykes, or Wall-like Masses of Rock.—In some parts of Great Britain the word 'dyke' means a *wall*, while in others it is understood as referring to a *ditch*. The geologist

Fig. 48.—Dyke of Igneous Rock (Basalt) traversing sedimentary strata.

applies the term dyke to wall-like masses of igneous rocks which have flowed into, filled up, and cooled and hardened in more or less vertical fissures in other rocks (see figs. 48 and 49).

Dykes are of course most common in volcanic districts. Owing to the greater hardness of their materials they have resisted the forces of denudation better than the softer surrounding strata into which they were originally injected; and so we often find these dykes running like walls across a country, and standing many feet above the neighbouring rocks.

Dykes are larger than *intrusive veins*, which latter term is applied to the narrower bands of igneous rock which fill irregular cracks. Some dykes have a remarkable extension; that known as the *Cleveland Dyke* of the North of England can be traced for 90 miles, extending from near Scarborough in a north-westerly direction to the south of Scotland. Of active

Fig. 49.—Section of Volcanic Rocks at St. Helena, showing Dykes of injected lava traversing volcanic ashes.

volcanoes Etna is famous for the number and size of the dykes exposed round the crater.

Hade or Inclination of a Fault.—The lines of dislocation of the rocks, known as *faults*, are nearly always inclined more or less from the vertical. The side of the fault on which the strata have dropped to a lower level is known as the 'downthrow' side; and the other, of course, as the 'upthrow'. The amount of depression must be measured *vertically*, and not along the slope of the fault-fissure. The amount of inclination of a fault is measured, in degrees, *from the vertical*; and the inclination itself is called the *hade* of the fault. As a rule the fault hades or inclines in the direction of the downthrow, and such faults are said to be *normal* (see fig. 45).

Sometimes (though but rarely) the contrary is the case, and the fault is then called a *reversed* or upthrow fault (fig. 50).

Ordinary faults not only separate strata vertically, but laterally as well; and the amount of side displacement of the strata, measured horizontally, is called the *lateral shift* of the beds.

Faults often run across a country for long distances. Thus the Pennine Fault extends from the south of Scotland into Derbyshire, a distance of 130 miles, the downthrow being to the west. The Bala Fault of North Wales has an extension of 60 miles; the downthrow is to the north, on which side the same beds are found 3000 feet lower than the corresponding strata on the south or upthrow side of the fault.

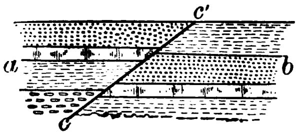


Fig. 50.—Reversed Fault: *c*, *c'*=line of fault; *a*=upthrow side; *b*=downthrow side of fault.

The knowledge that, as a rule, "the fault hades to the downthrow" is of great service to miners in determining whether it is of any use to mine deeper in search of a continuation of the seam of coal or the lode which they may have been working, but which is cut off by a fault. If the seam, &c., which has been worked is on the "upthrow" side, there is good reason for believing that a continuation of it will be found by sinking a shaft to a greater depth on the "downthrow" side of the fault.

During the production of a fault the rocks on one side of it are naturally rubbed, more or less, against those on the other, and in this way they often become grooved and polished, producing an appearance known as *slickensides*.

In some faults the rocks on the opposite sides of the line of dislocation fit so tightly together that the blade of a knife could not be inserted in the crack; but in others the fault-fissure may be several feet or even yards in width. In the latter cases, however, the fault-fissure is always filled up by broken pieces of the neighbouring strata (known as 'fault-rock'), or by mineral matter carried or deposited by running water.

Tracing and Mapping Faults.—It might be expected that faults would be very visible at the surface. As the strata have been displaced in some cases to the extent of thousands of feet vertically, it seems as if a line of cliffs or hills ought to be seen along the elevated or "upthrow" side of a fault. Now in Colorado this is actually the case, for the upthrow side of each great fault is indicated by an abrupt rise of the ground; but this is an exceptional case, and is due to the fact that in Colorado the faults are of (comparatively) recent origin, that little rain falls there, and that the faults have been produced since the elevation of that country above the sea. As a rule we cannot trace or map a fault by any appearance on the surface of a country, for by the action of the sea (during the time when the land was slowly rising above the waves) and by the subsequent action of the other forces of denudation—rain, frost, &c.—the strata on each side of an ordinary fault have been reduced to the same level. The soil, the vegetation, and the fact that most rocks are more or less decomposed to a depth of many feet below the surface, also prevent, as a rule, any distinct appearance of a line of fault running across a country.

The geologist who maps a fault has to rely, therefore, chiefly upon the sections of rocks exposed in mines, quarries, cliffs, railway-cuttings, deep ditches, the sides of valleys, river courses, &c. From his study of the strata, more especially of their dip and strike, he is enabled to say in what direction they ought to extend; and if, in that direction, he finds them *suddenly replaced* by a new set of rocks, he suspects the existence of a fault by which the beds have been displaced, and he searches along the line of junction for further evidence, and generally succeeds in finding sections which expose a faulted junction.

Ripple-marks in Rocks.—Every one who has walked on a sandy beach must have noticed the undulations or furrows left in the sand by the receding tide—ripple-marks as they are called. Precisely similar appearances can be noticed in many old sandstones of Cambrian, Silurian, Triassic, &c., age, telling us that the strata in which they occur were deposited in

shallow water. The sun must have shone on the old beach and hardened the furrowed sand. Then the next advancing tide brought a further quantity of sediment, which was deposited upon this sand, so covering up and preserving its markings.

Similar furrows are produced by the *wind* blowing over sandy deserts, and some of the markings in the Triassic strata may be due to this cause; but in most examples these ancient ripple-marks were undoubtedly produced by the agency of water, for we often find fragments of marine shells associated with them.

Rain-pittings on Rock Surfaces.—When rain falls heavily on a surface of soft mud or sand each drop makes a little round mark or depression. If the rain is driven sideways by the wind, the little hollow has its margin raised on the side towards which the wind was blowing. These rain-prints, or rain-pittings, are common in the Cambrian and in the Triassic strata. They tell us of surfaces—probably sea or lake shores—exposed to the weather; and that the wind blew and the rain fell millions of years ago just as they do at the present day.

Sun-cracks in Rocks.—In a hot and dry summer every dried-up pool and every muddy sea-shore is seen to be crossed by a number of cracks and fissures, due to the contraction of the mud or muddy sand when its moisture evaporated. Similar sun-cracks can be found in many old rocks, and they tell us of the ancient shore-lines which then existed; for as long as the stratum was covered by water such markings could not be formed in it. They owe their preservation to the fact that the rising tide brought more sediment, which filled up the cracks and covered over the hardened mud.

Along with these ripple-marks, rain-pittings, and sun-cracks, we sometimes find in the stratified rocks the *footprints* or other evidences of the passage of animals over these old surfaces. The Triassic sandstones contain impressions singularly like those of the feet of birds, and others which undoubtedly were made by reptiles. The tracks and burrows of annelids (worms) are also of common occurrence in sandy rocks.

SECTION C.—COMPOSITION OF THE PRINCIPAL ROCKS AND COMMON ROCK-FORMING MINERALS.

CHAPTER IX.

CRUST OF THE EARTH—ELEMENTARY BODIES—MINERALS.

Chemical Composition of the Crust of the Earth.—The researches of chemists have made us acquainted with about seventy-five simple substances or elements. Each of these chemical elements is composed of one kind of matter only, differing in some respect from every other kind of matter. Thus we call iron an element, because it is composed of nothing but iron, and by no known method can any other kind of matter be extracted from it.

Of the seventy-five elements there are sixteen which are called non-metals. These are:—

Oxygen	Gases.	Iodine	Solids
Hydrogen	Gases.	Carbon	Solids
Nitrogen	Gases.	Boron	Solids
Chlorine	Gases.	Sulphur	Solids
Fluorine	Gases.	Silicon	Solids
Argon	Gases.	Phosphorus	Solids
Bromine—A liquid.		Arsenic	Solids
		Selenium	Solids
		Tellurium	Solids

The metals are about sixty in number. They are distinguished from the non-metals by having a "metallic lustre", and by being good conductors of heat and of electricity. The most common metals are iron, lead, copper, tin, gold, silver, &c.

Of the seventy-five elements, about forty-five are *rare*—that is, they occur in small quantities only, and are seldom met with.

The Most Abundant Elements.—Of all the elements the gaseous substance known as *oxygen* is by far the most abundant. It forms (by weight) nearly one-half of the rocks which compose the earth-crust, eight-ninths of water, and one-

fifth of the air. Next to it comes silicon, which constitutes more than one-quarter of the earth-crust, and then follow the other elements named in the following table:—

Table showing the Chemical Composition of the Crust of the Earth.

Oxygen, ...	480
Silicon, ...	290
Aluminium,	80
Iron,	60
Calcium, ...	30
Sodium, ...	20
Potassium,	20
Magnesium,	15
Hydrogen,	2
All the remaining elements,	3
	1000

Chemical Compounds.—In the crust of the earth it is an exception to find any substance in its simple or elementary state. The elements combine with one another to form *compounds.* Thus water is a chemical compound of the elements hydrogen and oxygen; carbonate of lime is composed of the three elements, carbon, oxygen, and calcium; quartz, of the two elements known as silicon and oxygen; and so on. When a compound forms part of, or is formed by, some living thing —some animal or plant—it is called *organic*; all other compounds are called *inorganic.* Thus sugar is an organic compound (it is composed of hydrogen, oxygen, and carbon), because it was formed by a plant; but quartz is inorganic. Naturally most of the substances of which rocks are composed belong to the inorganic class.

What is a Mineral?—A mineral is generally defined as an inorganic substance possessing a definite chemical composition and usually assuming a particular crystalline form. Exceptions to this are coal (compressed vegetable matter), amber (a fossil resin or gum), carbonate of lime (which has been produced by animals inhabiting the sea, as most molluscs), &c. Elements may occur as minerals; thus in volcanic districts

we often find beds of the yellow element named *sulphur*; *gold* almost always occurs alone or uncombined as grains in quartz, &c.; *coke* is an amorphous (without definite shape) and the *diamond* a crystalline form of *carbon*; *iron* is also found in small masses which have fallen from the sky as meteorites. But most minerals are compound bodies, consisting of two or more elements chemically combined.

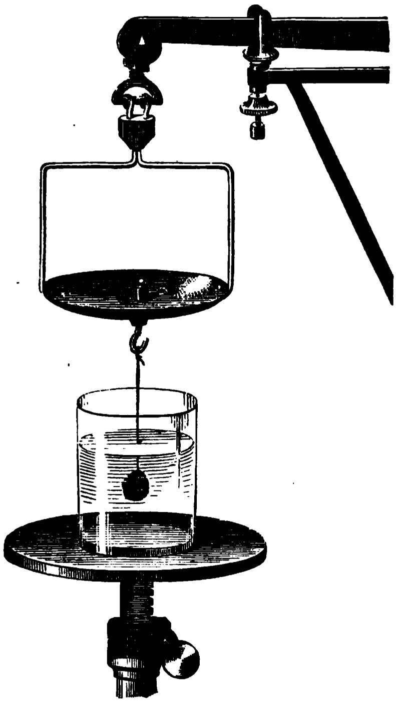


Fig. 51.—Specific Gravity of Solids. The rock-fragment is suspended by a fine wire from one pan of a delicate balance.

Tests Applied to Minerals.—Some thousands of mineral substances are now known, although many of these are of but rare occurrence. To be able to name even the common minerals at sight it is necessary to become personally acquainted with them by the examination of specimens. But there are a few simple tests by which the probable name and nature of any common mineral can be determined.

Specific Gravity of Minerals.—It is important to know the *specific gravity* of a mineral, *i.e.* its weight as compared with that of an equal volume of water. This is done by weighing the mineral first in air, and then when suspended in water by a slender thread. Divide the weight in air by the loss of weight in water, and the resulting number represents the specific gravity of the mineral. Thus if a crystal weighs

100 grains in air, but only 75 grains when hanging in water, its specific gravity equals 100 divided by 25, = 4 (see fig. 51).

We must also note the *colour* of the mineral, and the mark or *streak* which it leaves when drawn across a plate of white unglazed porcelain.

Minerals also differ in *hardness.* In the following table those possessing a similar hardness are grouped together and numbered. By adding a number to our description of any mineral we indicate at once its comparative hardness—the number (1) standing for the softest, and the number (10) for the hardest minerals known.

Minerals arranged according their hardness:—

1	2	3	4	5
Talc. Graphite.	Rock-salt. Muscovite. Selenite. Gypsum.	Calcite. Biotite. Galena.	Fluor-spar. Dolomite.	Apatite.
6	**7**	**8**	**9**	**10**
Orthoclase. Hornblende. Augite. Hematite. Magnetite.	Quartz.	Topaz.	Sapphire. (Corundum or Emery).	Diamond.

Crystals.—Minerals also *crystallize* in many different shapes, but all these shapes or forms can be arranged under *six* systems.

Chemical Composition of Minerals.—Of course the best way to ascertain the true nature of an unknown mineral is to make a careful *chemical analysis* of it, so as to see of what elements it is composed, and in what proportions. The chemical composition of each mineral will be given as part of its description.

Common Minerals: (1) Quartz.—Hardness, 7; specific gravity, $2\frac{3}{4}$; chemical composition, oxide of silicon, usually called *silica*; chemical formula, SiO_2.[1] Pure quartz (fig. 52) is colourless and transparent to white, but it is often coloured by small quantities of iron or other impurities. Abundant

[1] That is, the smallest portion or *molecule* of quartz is composed of one atom of silicon (Si) united with two atoms of oxygen (O).

as an ingredient of such rocks as granite, gneiss, &c., and also occurs filling veins and cavities in rocks.

Opal and Chalcedony.—The oxide of silicon (usually called "silica"), SiO_2, is one of the commonest of all minerals, and when it is *crystallized* it is known as *Quartz*. But we also get the same substance in the *uncrystallized*, amorphous, or colloid ("jelly-like") state, and it is then called *Opal*. Both the hardness ($5\frac{1}{2}$ to $6\frac{1}{2}$) and the specific gravity ($2\frac{1}{5}$) of opal are rather less than those of quartz. Some varieties of opal show a fine play of colours (due to the presence of small quantities of other minerals as impurities), and these rank as precious stones.

Opal contains a variable amount of water, ranging from 3 to 16 per cent. Large quantities of opal occur in volcanic rocks. Nearly all specimens of this mineral exhibit "opalescence", having one colour by reflected light and another by transmitted light. Some forms of opal exhibit a fine play of colours, as in fire-opal. Opal is an unstable form of silica, and in this mineral there is a constant change slowly going on from amorphous opal to crystalline quartz, as in the variety known as "semi-opal".

Chalcedony consists of a mixture of the colloid (opal) and the crystalline (quartz) forms of silica, the quartz-crystals being extremely small, so as only to be visible under the microscope. Flint and chert are impure forms of chalcedony: jasper is an opaque variety; while agates are translucent varieties of this substance. Chalcedony often occurs lining cavities in lavas, and in limestones, &c. It is not so hard as quartz, and its specific gravity is not quite so high.

(2) The Felspars.—Felspar is the name applied, not to a single mineral, but to a family of minerals. Their hardness is represented by the number 6, so that they can be just scratched by the point of a penknife; and their specific gravity varies from $2\frac{1}{2}$ to $2\frac{3}{4}$. They have a platy structure and a glossy appearance; usual colours white, or some shade of gray or red.

Orthoclase felspar is chemically a silicate of alumina and potash. It is distinguished from all other felspars by its right-angled cleavage, and by the surfaces of the crystals never being

striated. It is usually white, gray, or flesh-coloured. It is commonly found in such rocks as granite, syenite, trachyte, &c. The term *orthoclase* is derived from the Greek *orthos*, straight; and *klasis*, cleavage.

Plagioclase felspar includes several varieties, which are mostly characterized by fine lines (*striæ*) crossing the faces of the crystals. The cleavages of the crystals are never at right angles, and hence the name plagioclase — from *plagios*, oblique; and *klasis*, cleavage. Chemically, the plagioclase felspars consist of silicate of alumina united with either of the silicates of soda or of lime, or with both. The plagioclase felspars vary much in colour, and are found in many igneous rocks, as diorite, andesite, &c.

Fig. 52.—Quartz Crystals: hexagonal prisms, each terminated by a hexagonal pyramid.

(3) The Micas.—The micas form another group of minerals, distinguished by the ease with which they can be split into extremely thin layers, and by their pearly lustre. Their chemical composition is very complex.

Muscovite, common or potash-mica, is composed of silica, alumina, and potash. Its hardness is between 2 and 3, so that it can be easily cut with a knife. In Russia this potash-mica occurs in such large and transparent plates that the peasants use it in their windows, and hence it is called "Muscovy Glass". It is a common mineral in granite, &c., and its shining silvery flakes are often seen on the surfaces of sandstone.

Biotite is a magnesia-iron mica of a dark colour (dark-green

to black), commonly found in thin scales in many granites, gneisses, and schists; also occurs in basalt, trachyte, &c.

(4) Hornblende.—This is a dark-brown, black, or greenish-black mineral, which occurs both as short crystals, and in long needle-like forms. Hardness, 5½; specific gravity, 3. Chemically, it is composed of silica, alumina, magnesia, lime, iron, and manganese. Hornblende occurs in acidic and intermediate rocks; such as syenite, diorite, and granite.

(5) Augite.—This is a common mineral closely allied to hornblende, being of much the same chemical composition, &c. It is found in basalt and other basic rocks.

Nature of Minerals formed by Metamorphic Action.—The materials of both those igneous and those aqueous rocks which have undergone metamorphic changes are liable to become re-crystallized by the action of the heat generated by contact with the molten igneous matter, and by the pressure to which the rocks have also been subjected.

As a result of this re-crystallization new minerals are formed, which often completely alter the texture and character of the rock. Thus we may trace an amorphous limestone towards an igneous boss and see the gradual introduction of new minerals in the limestone; until finally when in contact with the igneous rock we see a crystalline mass of idocrase and garnet which differs completely from the limestone which once existed there, and from which these minerals have been derived.

Iron-pyrites is a mineral commonly found in slates where they abut against igneous rocks. Garnets, mica, and the mineral chiastolite, with andalusite and staurolite have all been observed in altered slaty rocks, and have all resulted from metamorphic changes.

Many altered limestones contain veins of the mineral serpentine; and flakes of mica, green crystals of augite, olivine, plagioclase felspar, and idocrase have also been observed in them.

In the mica-schists, the minerals staurolite, andalusite, and kyanite are occasionally found. They are all silicates of alumina; and are typical examples of the minerals formed in rocks by metamorphic alterations.

Magnetite, and the dark-green mineral known as epidote, are found in chlorite schists, and also in serpentine schists.

In gabbro-schist, the mineral hornblende has been formed during the alteration of the rock; and under the microscope it is seen to occur as bands and strings of crystals.

In many cases these secondary minerals are but incompletely formed, and they often differ considerably (especially in their optical properties) from the corresponding normal minerals which have not resulted from metamorphic changes.

CHAPTER X.

Igneous Rocks: their Composition and Classification.

What is a Rock?—Any solid substance which forms a bed, layer, or mass as a part of the crust of the earth, is called by geologists a *rock*. Hardness has nothing to do with the term; beds of soft clay and yielding sand are considered by the geologist to be rocks just as much as granite and slate.

Classification of Rocks.—There are two main classes of rocks; the *igneous* or "fire-formed", and the *aqueous* or "water-formed"; and these are linked together by a third class, the *metamorphic* rocks, which includes all those rocks which have been *altered*—whether they were originally igneous or aqueous—but yet not so greatly changed as to destroy all traces of their original nature.

Crystalline, Vitreous, and Clastic Rocks.—Any rock which is seen (either by the naked eye, or through the microscope) to consist of crystalline minerals, has either consolidated from a state of fusion (igneous rocks), or has resulted from the alteration of pre-existing rocks (metamorphic rocks).

(*a*) When the rock consists of crystalline minerals alone, as in the case of granite and gabbro, it is said to be 'holocrystalline'; and where one of the crystalline constituents has developed on a larger scale than the rest, the rock is said to possess a "porphyritic structure".

The crystalline texture of these holocrystalline rocks shows every degree of coarseness, from microscopic crystals to those of several inches in length.

In many of the rocks known as diorites, dolerites, and gabbros we have well-developed crystals of felspar; while around and between them there has settled down in large crystals another mineral constituent—augite, or hornblende—which covers considerable areas and acts as a binding material to the entire rock. In such cases the augite frequently encloses the felspar, and has evidently crystallized out *after* the crystals of the latter mineral were formed. This structure is termed 'ophitic', and derives its name from the dolerites of the Pyrenees, which were once known as 'ophites'.

Where the crystals are arranged so as to form spheroidal aggregates, usually radiating from a centre, we have "orbicular" structure. This is well shown in the orbicular diorite of Corsica.

The igneous crystalline rocks have usually solidified at great depths in the earth's crust, and under great pressure. This is most certainly true of the holocrystalline rocks. The more slowly the rock cooled, the larger and more perfect the crystals would be.

(*b*) Many crystalline rocks, however, when examined under the microscope are seen to contain a glassy matrix. This matrix binds together the various mineral constituents of the rock, and represents that portion which did not crystallize out. We have here, then, a rock consisting of crystals and of uncrystalline or amorphous glass. Such a rock is said to have a 'hemicrystalline' structure. Rhyolite, trachyte, and andesite are good examples.

Many of these hemicrystalline rocks are scoriaceous or cindery (resembling in appearance the slag of our iron furnaces), a good evidence of their volcanic origin. Their cavities and pores are frequently filled in part or altogether with certain minerals which are alteration products, such as calcite, chlorite, and zeolites. These being usually white in colour and ovoid in outline resemble almonds, and are termed 'amygdules', the rock itself being said to possess an amygdaloidal structure.

(*c*) *Vitreous or Glassy Rocks.*—To the unaided eye, many igneous rocks appear to be wholly glassy and compact. Under the microscope, however, they are seen to contain scattered

Fig. 53.—Perlitic Structure (magnified twenty diameters).—After diagram by J. Lomas.

and frequently broken and corroded crystals of quartz, felspar, hornblende, and mica. In addition, they invariably contain minute rods, or groups of rods, termed 'microlithes', these being the beginnings or nuclei of crystals which were arrested in their growth by the solidification of the glassy rock.

Fig. 54.—Spherulitic Structure.—After G. A. J. Cole. (Reproduced from the Quarterly Journal of the Geological Society.)

A characteristic feature of these vitreous rocks is the perlitic structure, due to fine joints in the rock, the spaces between the joints being broken up by delicate curved and concentric cracks (see fig. 53).

When the microlithes, as mentioned above, crystallize out in globular aggregations, presenting in section a radial and concentric arrangement we have what is known as spherulitic structure. This should be compared with the somewhat similar but more conspicuous orbicular structure of some crystalline rocks: (see fig. 54).

In the devitrified or stony rhyolites of the Ordovician rocks of Caernarvonshire, and at the Yellowstone Park in North

America, very large spherulites occur. These are often many inches in diameter, and have been hollowed out by corrosive vapours. They are termed *lithophyses* ("stone bladders"). The hollow lithophyses have sometimes subsequently been filled with opal, quartz, and chalcedony, introduced by and deposited from percolating waters.

As the vitreous rocks are of volcanic origin, we should expect to find in them those structures peculiar to liquids which have solidified whilst in motion. Accordingly we have in such rocks both fluidal structure, and banded structure; the microlithes being arranged in lines and bands parallel to the direction of flow of the molten lava. A scoriaceous structure due to the drawing out of the viscid lava by expanding gases is also of common occurrence.

Pumice, rhyolitic and andesitic glass, together with the basaltic glass known as tachylite, belong to this group of rocks. A selvedge or edging of tachylite is sometimes found on basaltic dykes and veins, where the molten rock has been rapidly cooled by contact with the surrounding rocks into which it was ejected.

(*d*) *Clastic Rocks.*—By 'clastic' rocks we understand those fragmental rocks, whether of volcanic, chemical, inorganic, or organic origin, which have been laid down under water, or arranged by aeolian agencies. Fragmental rocks which consist of volcanic materials, and which show signs of having been deposited in water, are termed *pyroclastic.*

Volcanic Sands include aqueous deposits which have obtained their materials from some neighbouring volcano. The ancient diabase tuff of Porthdinllyn, in North Wales, described by Prof. Bonney, is simply a compacted volcanic sand.

Volcanic Tuffs and Agglomerates.—These consist of fragments of volcanic rocks, usually of angular and bomb-like forms, mingled with fragments of pumice and volcanic glass, all cemented together by fine dust and by finer particles of the the same materials. With these we may have fragments of aqueous rocks which were thrown out of the volcano along with the particles and fragments of igneous origin.

Beds of volcanic sand and tuff vary considerably in thick-

ness even within a small area, and frequently show distinct signs of stratification due to the sifting action of the water into which they happened to fall. Some even contain fossils, as the Ordovician ashes which form the top of Snowdon.

THE IGNEOUS ROCKS.

Nature of the Igneous Rocks.—The igneous or fire-formed rocks are the products of volcanic action, either ancient or modern. An active volcano, such as Vesuvius or Stromboli, ejects or erupts from its crater immense quantities of gaseous

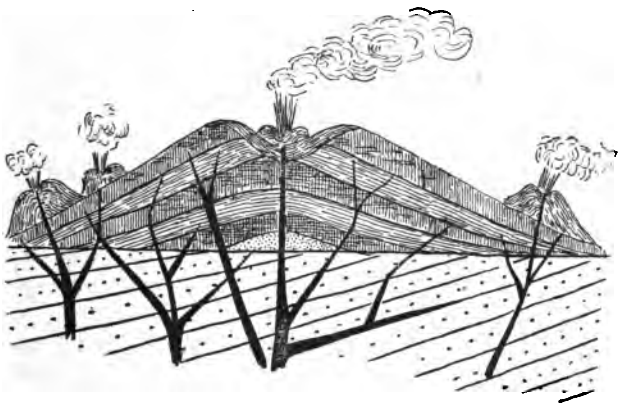


Fig. 55.—Ideal Section through an Active Volcano, showing parasitic cones, &c.

matter, which mingles with the atmosphere; and it also ejects a great quantity of solid matter in a state of fine division, which falls upon and around the crater as *volcanic ash*. This volcanic ash may be carried hundreds of miles by the wind; but when it falls to the ground, or into seas or lakes, it forms stratified rocks, which in their banded appearance may resemble ordinary aqueous rocks, from which, however, they differ in their chemical composition, and in the (usual) absence of fossils. Such beds of volcanic ashes, whether ancient or modern, are known as *tuffs*.

An active volcano also pours forth at intervals floods of

melted rock or lava. And *underneath* each volcanic cone lies a reservoir of molten rock. Instead of rising vertically up the pipe or vent into the crater, this molten rock often finds it easier to push its way *sideways*, intruding upon and breaking through the neighbouring stratified rocks; the sheets of hot liquid matter thus forced in between the sedimentary strata also baking and altering the latter (see fig. 55).

In the case of the existing volcanoes we can never hope to see these *subterranean* igneous rocks. But volcanoes appear to have been at work during all the past stages of the world's history. Now, the cones of these old volcanoes have in most cases been removed by the forces of denudation acting through long periods of time; and the *roots*, so to speak, of the old cones and craters have thus been uncovered and exposed.

In the Auvergne district of Central France the cones and craters of the extinct volcanoes which were formed there during the Miocene period are still wonderfully well preserved. In the Western Isles of Scotland—Mull, Skye, &c.—volcanoes of a somewhat earlier (Eocene) age have had their cones removed, and their basal framework is now exposed to the light of day. Of still older volcanoes the rocks of North Wales and the Lake District afford abundant traces.

Volcanic Rocks associated with Strata of different Geological Periods.—It must be clearly understood that the effects of volcanic action—the dykes, veins, lava-streams, volcanic ashes and agglomerates—are not limited to the recent or historical period.

Without exception every geological period from the Archæan to recent times has had its active volcanoes; and the sedimentary rocks of each successive geological age or epoch are in some locality or other certain to be found intercalated with beds of volcanic material.

The Archæan gneisses and the Torridon Sandstone of the north-west of Scotland contain beds of volcanic tuff, and are traversed by volcanic dykes.

During the Cambrian Period, the altered andesites (diabases) and tuffs of Pembrokeshire were ejected.

The Ordovician Period was one of extraordinary volcanic activity, for the enormous sheets of rhyolitic and of andesitic lava composing Snowdon, Cader Idris, the Rivals, and Carn Madryn in North Wales were erupted chiefly during the laying down of the Arenig and Caradoc beds.

The Upper Silurian Period was one of comparative quiescence, although in the west of Ireland a few volcanoes were still active.

In Scotland, during the deposition of the Old Red Sandstone, many volcanoes were in active eruption. The Sidlaw and Ochil Hills (which are of Old Red Sandstone age) consist of lava streams and volcanic tuffs.

The Carboniferous epoch, especially the earlier part of it, saw a prolonged period of volcanic activity. The volcanic necks and toadstones in the Mountain Limestone of Derbyshire (consisting of basalts, andesites, and trachytes) were formed at this time.

In the south-west of Scotland numerous volcanoes existed in Permian times; but from that period to early Tertiary times the British Isles were free (or all but free) from volcanic disturbances. In other words, no traces of Mesozoic volcanoes have here been met with. The Triassic, Jurassic, and Cretaceous Periods of the Continent and elsewhere, however, were marked by outpourings of contemporaneous lavas.

In Eocene times the great plateaux of basalt forming Co. Antrim, the Giant's Causeway, the Isle of Skye, and Fingal's Cave were ejected.

During Miocene times the now extinct volcanoes of the Eifel district, and of Auvergne, were formed.

Later still (in Late Tertiary times) the great outpourings of basalt in Idaho and Nevada (two of the western territories of the United States) took place.

Classification of Igneous Rocks.—In endeavouring to form some satisfactory scheme of classification for the hundreds of varieties of igneous rocks which are now known, we must consider mainly their chemical composition and the conditions under which they solidified.

Taking the latter point first, we distinguish the coarsely crystalline *deep-seated* rocks, like granite, &c., which cooled slowly and under great pressure deep down in the earth (having formed part of the "reservoir" or "root" of some old volcano), from the more compact or porous lavas, tuffs, &c., which have at some time or other been ejected from craters. The former are known as *Plutonic*, and the latter as *Volcanic* rocks.

Chemically speaking, the igneous rocks are all composed of silica (which here plays the part of a powerful *acid*), combined with the *bases* alumina, potash, soda, and lime; iron is also frequently present.

The *Acid* igneous rocks are therefore those which contain the greatest percentage of silica; and the *Basic* igneous rocks those which contain the least.

The acid rocks contain from 65 to 80 per cent of silica; the basic rocks from 45 to 55 per cent only.

Other rocks contain from 55 to 65 per cent of silica, thus *lying between* the acid and the basic groups; we accordingly term them *Intermediate.*

The following table of the igneous rocks is based on the two points we have already mentioned, viz. (1) chemical composition, and (2) position—whether deep down or at the surface—at time of solidification.

TABLE OF THE IGNEOUS ROCKS.

	Acid.	**Intermediate.**		**Basic.**
	Quartz+O. Felspar +Mica.	**SUB-ACID.** **O. Felspar +Hornblende.**	**SUB-BASIC.** **Plag. Felspar +Hornblende.**	**Plag. Felspar. +Augite +Iron.**
Volcanic.	Obsidian. Rhyolite.	Trachytic Pumice. Trachyte.	Andesitic Pumice. Andesite.	Basaltic Pumice. Basalt. Dolerite.
Plutonic.	Granite.	Syenite.	Diorite.	Gabbro.

Granite.—Granite may be taken as the type of an acid plutonic rock. The crystals which compose it are distinctly visible, and we can distinguish the hard glassy-looking *quartz* from the opaque white or pink *orthoclase felspar*, and still more readily from the flat easily-splitting plates of *mica*, which may be either white and silvery (muscovite, or potash-mica), or dark-brown to black (biotite, or magnesian-mica). See fig. 56.

Fig. 56.—Thin Slice of Granite as seen by transmitted light under the microscope. It is composed of the minerals quartz, felspar, and mica.

Granite usually occurs in large bosses, and is often seen to have broken through the surrounding stratified rocks, into which it sometimes sends veins. It must have consolidated at a considerable depth below the surface—perhaps two or three miles or more—so that its present appearance at the surface (often forming the highest parts of mountain chains) is a testimony to the forces which have produced elevation and denudation.

Fig. 57 is a reproduction of a photograph of Pu Tor, Dartmoor. It illustrates admirably the effects of sub-aerial denuding agencies upon large masses of jointed igneous rocks. Pu Tor, and indeed all the Dartmoor Tors, are composed of a grayish granite which is traversed by joints which are approximately at right angles to each other. Along the horizontal and vertical joints 'weathering' goes on rapidly; these joints being lines of weakness along which the denuding agents (such as rain, frost, &c.) find a ready access to the substance of the rock. As a result of this 'weathering' we have the production of large slabs, each defined by joint planes, and rising one above the other like tiers of loose masonry. Sometimes a block of granite becomes so acted upon as to be poised by a point upon the rock below it, and it can then be moved by the hand; as in the case of the "rocking stones", or

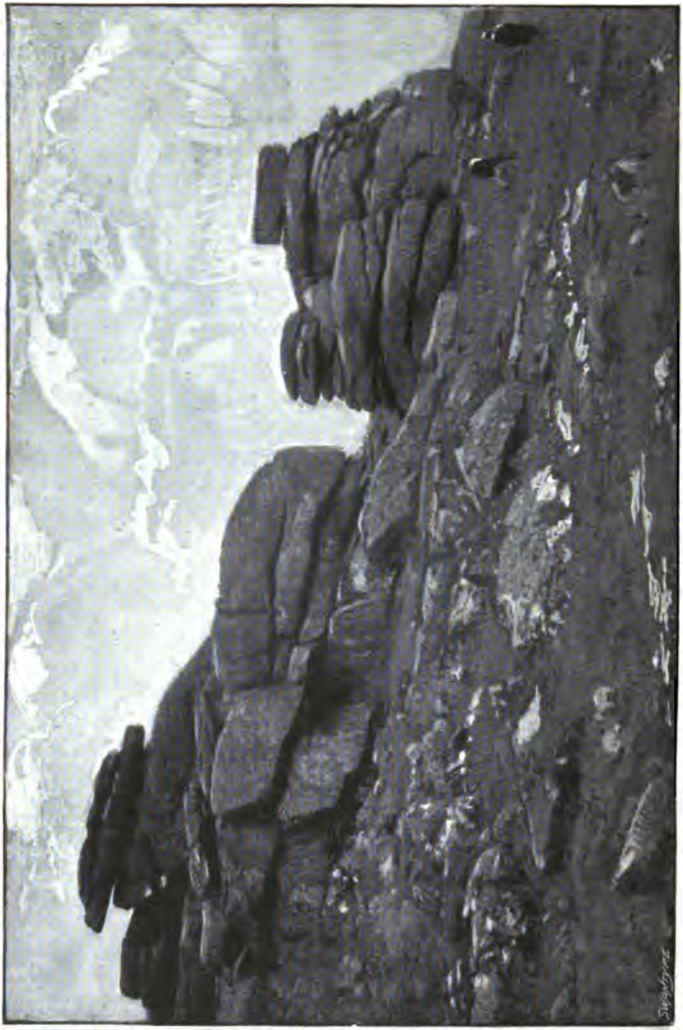


Fig. 57.—Pu Tor, Dartmoor; an illustration of the 'weathering' of granite.

"logans", of which many good examples may be found in Cornwall, as near the Land's End, &c.

In England granite forms much of Dartmoor, and occurs at five other places in Devon and Cornwall. It is largely quarried both there and at Mountsorrel in Leicestershire. The same rock forms much of Anglesea; and it also crops out at several points in the Lake District, as Skiddaw, Eskdale, Shap, &c.

In Scotland there is much granite in the Grampians. It is largely quarried at Peterhead, north of Aberdeen; in the islands of Mull and Arran; and at Criffel and other points in the south-west counties.

The granites of Ireland mostly occur in the hills which fringe the coast; there are large masses in Donegal and Galway.

Varieties of Granite:—

(1) *Porphyritic Granite.*—In many localities, as, for example, at Dartmoor and Aberdeen, a variety of granite is found

Fig. 58.—Porphyritic Granite (from Cornwall).

throughout which are scattered large, tabular, and conspicuous felspar crystals of a grayish-white and flesh-red colour. Between and surrounding these large crystals we have a fine-grained and crystalline matrix of quartz, mica, and felspar. This rock is termed a "porphyritic granite", and during its solidification from a molten mass the felspar has evidently crystallized out at two distinct periods. The large crystals were the first to form, the smaller felspar crystals within the matrix crystallizing out afterwards. Any variety of rock in which large and

distinct crystals of some particular mineral stand out conspicuously from a fine ground-mass is said to be "porphyritic", or to possess a "porphyritic structure" (see fig. 58).

(2) *Pegmatitic Granite.*—A variety of granite is sometimes found which consists almost wholly of orthoclase felspar and quartz. The crystals of these two minerals do not show true crystalline outlines, but are intergrown with one another, with a tendency for their longer axes to be more or less parallel. This variety of granite is termed "pegmatite", and the felspar and quartz probably crystallized out at the same time. *Graphic Granite* is simply a pegmatite in which the intergrowth of the two minerals was very complete, so that they resemble (when the rock is cut and polished) writing in Hebrew characters. When the above structure is on a microscopic scale the rock is known as a *micro-pegmatite.*

(3) *Drusy Granite.*—In ordinary granite it is very rarely that minerals exhibiting their true crystalline faces and outlines are met with. But within some granites circular and oval cavities occur which are known as "druses". Within and attached to the sides of these druses good and well-defined crystals are often found of those minerals which form the granite. Thus we get perfect crystals of felspar, quartz, and mica inside these "druses", together with certain other minerals, such as topaz and beryl. The various crystalline minerals do not fill the whole cavity, but form a lining to the druse. Such granites (which contain cavities) are termed drusy granites. The granite of the Mourne Mountains in Ireland furnishes a good example of "drusy granite".

Granitic Veins.—Tongue-like inthrusts or veins of granite are frequently met with intruding into strata which belong to the older geological formations. These intrusive veins must have emanated from a more deep-seated and extensive granitic mass, and are frequently fine-grained. We also often find veins of this fine-grained rock (aplite) spreading into and across a coarse-grained granite.

In Cornwall veins of "elvan", a hemicrystalline mixture of quartz and orthoclase, proceed from the granite bosses of Dart-

moor, &c., intruding into the surrounding slates. At Brazil Wood, Charnwood Forest, Leicestershire, there occur branching

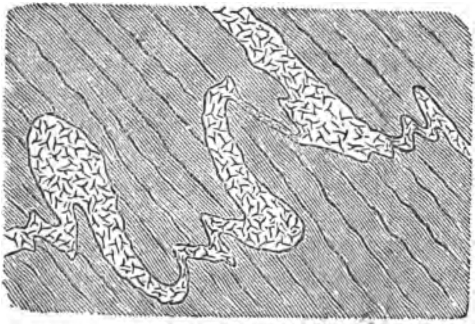


Fig. 59.—Contorted Granite-Vein in Gneiss.—After Ch. Callaway. (Reproduced from the Quarterly Journal of the Geological Society.)

veins of granite in the slates and gneissose schists of that district (see fig. 59).

Dykes.—Thick, more or less vertical and wall-like masses of plutonic rocks are occasionally met with, forming what are known as "dykes", in the rock-masses of the earth's crust. The materials forming these dykes must have been injected or forced while in a molten or liquid condition into the other rock-masses which they traverse.

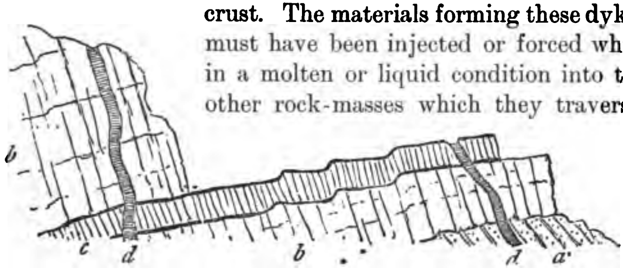


Fig. 60.—Section of dolerite sill (*b*, *b*) cut by another sill (*c*), both being traversed by dykes (*d*, *d*), stratified rocks are seen at *a*: Rudh' an Iasgaich, western side of Sleat, Skye. (Reproduced from the paper by Sir Archibald Geikie, in the Quarterly Journal of the Geological Society.)

They usually pass along the bedding-planes and joint-planes—these affording the lines of least resistance. At Hartshill and Nuneaton, in Warwickshire, thick vertical dykes of diorite are seen traversing the Cambrian quartzites. The gabbros of the Inner Hebrides are also penetrated by granitic dykes (see fig. 60).

Sills.—When a molten rock, whether plutonic or volcanic, thrusts itself *between and along the planes of stratification* of aqueous rocks, and there solidifies, it forms a sheet of rock which is roughly parallel to the layers of rock above and below. Such a sheet of igneous rock is termed a "sill". Sills of the plutonic rock known as *diorite* are plentiful in the Cambrian shales of Stockingford, near Nuneaton. The "Great Whin Sill" of the north of England is a sheet of basalt which has there intruded into the Lower Carboniferous strata. It can be traced for a distance of many miles.

Included Fragments in Granite.—Caught up by and entangled within the solidified rock forming the various granitic

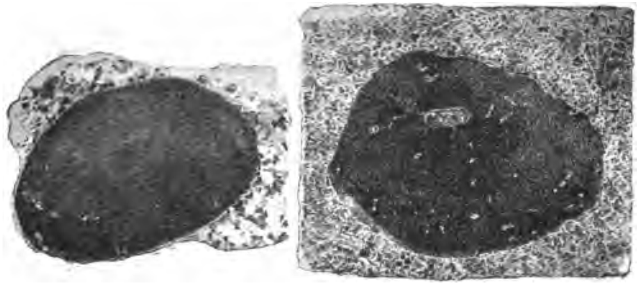


Fig. 61.—Inclusions in Granite.—After J. Arthur Phillips. (Reproduced from the Quarterly Journal of the Geological Society.)

masses, veins, dykes, and sills, there are sometimes found masses of rock which are quite different both in structure and in origin from the igneous rock which surrounds them. These masses of rock are termed "included fragments", and have been broken off and caught up by the molten rock as it forced its way through the surrounding strata. The included fragments are sometimes arranged in parallel lines, this being due to the onward flow of the molten rock previous to solidification. Fragments of slate, gneiss, hornblendic-schist and mica-schist are frequently found in granite veins and dykes. These fragments have usually been more or less altered, baked, and metamorphosed by the heat of the surrounding magma or

fluid rock; and in colour, &c., they often present a striking contrast to it. But we must be careful to distinguish 'nests' or segregation patches, or portions of the granite itself (which, owing to a finer crystallization, &c., may appear different to the main mass of the rock), from the true included fragments of other rocks. The latter are usually angular or sub-angular, and are more or less schistose, in addition to affording differences in colour and in texture as compared with the matrix in which they are contained. The 'nests' or concretionary lumps of the granite itself are rounded or oval, and are seen under the microscope to be composed of precisely the same minerals as the rest of the granite (see fig. 61).

Segregations in Granite, &c.—In granite and in certain other plutonic rocks, ramifying vein-like portions may sometimes be seen crossing the main mass of the rock. These veins are similar in mineral composition to the main mass of plutonic rock in which they occur, and can only be distinguished from it by their finer or coarser texture. They are termed "segregation veins", and represent that residual portion of the rock-mass which was the *last* to solidify, the material forming the veins having segregated, and been extruded, or squeezed out from among and between the crystalline minerals which were the first to solidify. This still molten residuum filled any fissures or rents which existed or which were produced in the pasty magma, and there formed veins on solidification. It must be clearly understood that the material forming a segregation vein was segregated while the surrounding rock was still in a pasty or unconsolidated and semi-fluid state. As a rule the rock forming the vein is coarser in texture than the parent mass; this is well shown in the granites of Aberdeen, where we have veins of a coarse pegmatite granite traversing the ordinary granite of the district, and insensibly merging into it. Large crystals of quartz, tourmaline, and mica occur in the coarser segregation veins in granite. On the other hand, in the granite of Mount Sorrel, in Leicestershire, the segregation veins which cross the parent mass are so fine-grained that they resemble a compact felspar.

Rhyolite (from the Greek *rheo*, I flow) is the name given to striped or banded lavas, which have the same general chemical composition as granite, and are composed of similar minerals. But these minerals are usually in much smaller crystals, and are intermingled with "glassy matter", thus forming a *hemi-crystalline* rock.

Obsidian is a glassy lava, its compact structure being due to sudden cooling, as when a lava stream flows into a sea or a lake.

Syenite.—Syenite is a holocrystalline plutonic rock, which received its name from the quarries at Syene, in Upper Egypt. It is composed mainly of the two minerals—orthoclase felspar and hornblende. Like granite, it occurs in large irregular

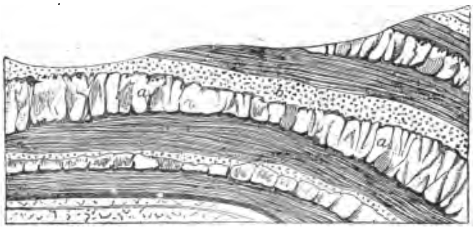


Fig. 62.—Intrusive Sheet of Basalt (*a*, *a*), which has altered the Sandstone Bed (*b*) above it, and also the Bed of Shale below it.

masses. It is quarried at several points on and near Charnwood Forest, in Leicestershire, and also forms the well-known island mass of Ailsa Craig, off the S.W. coast of Scotland.

Trachyte is the volcanic rock corresponding to syenite in the plutonic series. It is so named from its rough feel when the finger is passed over a newly-broken surface.

Trachytic Pumice is the frothy pumiceous surface-rock of a lava-stream composed of trachyte.

Diorite.—Diorite is a holocrystalline plutonic rock composed essentially of plagioclase felspar and hornblende. It has usually a greenish or greenish-black colour, so that the early geologists called it 'greenstone'. Diorite occurs in the Lake District; also at Brazil Wood (Charnwood Forest), and at several points in the Hartshill Range, near Nuneaton.

Andesite (so called from its frequent occurrence in the Andes mountains) and **Andesitic Pumice** are the volcanic representatives of diorite.

Gabbro.—Gabbro (the Italian name for similar rocks) is a crystalline plutonic basic rock composed of the minerals plagioclase felspar and augite. It forms bosses in Cornwall, Skye, and Mull; and occurs in still larger masses in Saxony.

Basalt and Dolerite.—Dolerite is the volcanic form of gabbro. When the crystals which compose the rock are visible to the naked eye, it is called dolerite; when the rock appears compact, it is called *basalt.*

Dolerite and basalt are black heavy rocks, which form intrusive sheets and dykes, cutting through and altering the stratified rocks of the districts in which they occur (see fig. 62).

The Rowley Hills in South Staffordshire are composed in part of dolerite and in part of basalt. In fact the one rock often passes into the other. Where it has cooled quickly it is usually a basalt; where more slowly, a dolerite. Basalt also forms the Salisbury Crags, near Edinburgh, and crops out at many places in the south of Scotland. In the north of Ireland it is seen in great sheets (of which the "Giant's Causeway" forms a part) along the coast of Antrim (fig. 63). The well-known Fingal's Cave, on the Island of Staffa, has been hollowed out by the waves in a mass of columnar basalt.

Fig. 63.—Columnar Basalt, from the Giant's Causeway, Antrim.

Tachylite is a glassy form of basalt due to a sudden cooling of the molten rock. It is therefore usually found forming a narrow edging on the sides of basaltic dykes, &c.

CHAPTER XI.

AQUEOUS ROCKS: THEIR COMPOSITION AND CLASSIFICATION.

The Aqueous Rocks.—Rocks which have been formed in water, whether they are composed of sediment like sand or mud, or of matter like carbonate of lime or silica which has been secreted from water by the action of living organisms, are known as *aqueous* rocks (Lat. *aqua*, water). These aqueous rocks are almost invariably *stratified*, because the materials composing them have been *strewed out* on the floors of seas and lakes.

Divisions of Aqueous Rocks.—We can first of all separate those rocks which are composed of detritus or sediment, from those which are of organic origin, having been formed by animals or plants.

Among the Sedimentary rocks we then distinguish those principally composed of clay (*argillaceous*, from the Latin, *argilla*, clay) from those which consist altogether or mostly of sand (*arenaceous*, from Latin, *arena*, sand).

In the Organically formed rocks we similarly separate those composed of limestone (*calcareous*, Lat. *calx*, lime) from those consisting mainly of carbon (*carbonaceous* rocks).

A few rocks have been Chemically formed, by the deposition of matter—mostly either carbonate of lime or silica—from the water containing it in solution.

Table of the Stratified Rocks.

I. Sedimentary or Fragmental (Mechanically formed).	1. Argillaceous	Mud. Clay. Shale.
	2. Arenaceous	Sand. Gravel. Sandstone. Grit. Conglomerate. Breccia.

II. Organically formed.	1. Calcareous......	Calcareous Ooze. Chalk. Coral-reefs. Shelly and other Limestones.
	2. Carbonaceous..	Peat. Lignite. Coal.
III. Chemically formed.	1. Siliceous........	Flint. Chert. Sinter.
	2. Calcareous......	Travertine. Stalactites. Stalagmite. Calcareous nodules and concretions.

Description of Aqueous Rocks.—Most of the rocks named in the above table have been described in Chapter VI. We therefore give here a brief account of the others only.

Flint is a gray or black very compact rock; hard as quartz; composed of silica. It occurs abundantly in lumps or nodules in the Upper Chalk. It was formed by the deposition of silica upon and around sponges, shells, &c.

Chert is an impure variety of flint.

Sinter is the name applied to the siliceous deposit seen around many hot springs, such as those in New Zealand, the Yellowstone Park in the United States, the geysers of Iceland, &c. The siliceous or flinty matter is brought up in solution in the hot water, from which it is deposited as the latter cools.

Calcareous Tufa or Travertine is a deposit formed in a similar way to sinter, but consisting of *calcareous* instead of siliceous matter. The well-known "petrifying springs" of Matlock and elsewhere bring up carbonate of lime in solution in their waters. A large part of this substance they deposit as soon as the water flows out of the spring, and any article placed in the stream soon becomes incrusted or "petrified" with the mineral. Around the springs of San Filippo in Italy

there is now a deposit of travertine which forms a hill a mile and a quarter long, and a third of a mile broad.

Stalactites and Stalagmite.—Rain-water is continually circulating through the crust of the earth, everywhere traversing and soaking through the rocks. Such water contains carbonic acid, which it has dissolved out of the air while falling from the clouds. This carbonated water running through limestone rocks is able to dissolve some of their carbonate of lime, which then exists in the water in the state of a soluble bicarbonate of lime. But when the water so charged issues out into the open air, as from a spring or cavern, some of the carbonic acid gas escapes, and consequently a part of the soluble bi-carbonate of lime returns to the state of a carbonate, and this insoluble carbonate of lime is then deposited on or around the point whence the water issues.

Fig. 64.—Cave with Stalactites and Stalagmites.

If such water drips from the roof of a cavern, every drop will leave a little limy matter behind, and in time a finger-like mass (or *stalactite*) will project downwards from the roof.

Falling on to and running over the floor of the cavern, the water there leaves still more of its lime, and this forms a crust or flooring which in time may become several feet in thickness. Such a layer of deposited carbonate of lime is called *stalagmite*.

Many caverns in limestone rocks, as those of Derbyshire, Yorkshire, Caldy Island (near Tenby), the Mammoth Cave of Kentucky, &c., present a most beautiful appearance when lighted up, owing to these projections and incrustations of stalactitic and stalagmitic matter, which vary in colour from a dazzling white to gray, yellow, and pink (see fig. 64).

Coal and its Formation.—Coal is a black, brittle, rather light rock which occurs in layers or seams varying from a few inches to thirty feet or more in thickness. It consists of compressed and mineralized vegetable matter, which grew long ages ago in swamps and low plains not much above the sea-level. By the growth and decay of generation after generation of plants in such spots a considerable thickness of vegetable matter was accumulated. The land there then undergoing subsidence, sediment—sand and mud—was deposited upon the vegetable matter to the thickness of hundreds (sometimes thousands) of feet. By the *pressure* of the matter above, and by the action of heat and moisture deep down in the earth, the compressed vegetable matter parted with much of its oxygen, hydrogen, and nitrogen, and became first lignite (wood-coal) and afterwards ordinary bituminous or house-coal. By further loss of gaseous matter bituminous coal passes into stone-coal or *anthracite*; and finally into *graphite*, which is almost pure carbon.

In some cases, however, the vegetable matter forming the coal-seams did not grow upon the area now occupied by it, but was *drifted* in clear water from some distance. We then find no underclay beneath the seams, and no signs of rootlets, &c. *Cannel Coal* was certainly deposited in this way.

Peat is a dark fibrous substance formed in recent times by the growth and decay of certain species of mosses, which grow rankly layer upon layer in damp boggy places.

Chemical Composition of Coal, &c.—The following table gives the results of the chemical analysis of the substances which form coal, and of coal itself:—

Elements.	Wood.	Peat.	Lignite.	House Coal.	Anthracite.
Carbon,...............	50	60	66	81	91
Hydrogen,............	10	7	6	4	3
Oxygen, Nitrogen, }	40	33	28	15	6
	100	100	100	100	100

It is clear that the *older* any coal-seam is, the more likely it

is to approach the state of anthracite. In regions, too, where the rocks are much disturbed and cracked (like parts of the South Wales coal-field), anthracite abounds, for there the coal has been most compressed, while at the same time its gases have been able to escape through the cracks or fissures.

Nodules and Nodular Concretions.—The term nodule is applied in geology to any rounded (usually pudding-shaped) lump or mass of naturally-formed inorganic matter. Such nodules are most common in beds of clay, limestone, and ironstone; but the flints found in chalk are good examples of siliceous nodules. It is common to find in the centre of a

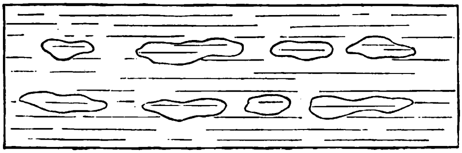


Fig. 65.—Calcareous Nodules in Liassic Limestone.

nodule some fragment of a fossil plant or animal. The formation of these rounded lumps, which may vary in size from an inch or two to several feet in diameter, is due to the chemical action which leads the particles of one and the same mineral to gather together as much as possible—this action is known as *segregation*; and the structure which it imparts to rocks, making them to appear to be composed of rounded lumps, is called *concretionary structure* (see fig. 65).

When the centres of segregation are close together, the nodules may unite laterally so as to form a continuous stratum. Of such chemically-formed deposits we have examples in the limestone beds near the base of the Lower Lias. The ironstone beds of the coal-measures frequently consist of similar continuous concretions; and the same thing is seen in the gypsum beds of the Trias.

Concretions.—Among the best-known examples of concretions we may mention the balls of iron-pyrites (brown without, but which are yellow inside when broken open) common in the Chalk and in certain other rocks; and the countless

flattened nodules of clay ironstone which abound in certain coal-measure shales. In the north of England the Magnesian Limestone (of Permian age) has often such a "concretionary structure" that a mass of it seen from a distance looks like a heap or a wall built of rough cannon-balls. All these cases result from that action of the chemical force, which leads matter having the same chemical composition to draw together, and to separate from other kinds of matter with which it may be mixed. Thus the silica which was originally diffused throughout the mass of the chalk gradually "drew together" and separated from the calcium carbonate (of which the bulk of the chalk is composed) to form rounded lumps of flint, and so on.

Ironstone.—The term ironstone includes several distinct chemical compounds, all of which, however, are capable of yielding metallic iron when properly treated.

(1) **Hæmatite,** red iron-ore, is an oxide of iron (Fe_2O_3). The same substance combined with water forms **limonite**—brown iron-ore.

(2) **Magnetic iron-ore,** or magnetite, is another iron oxide (Fe_3O_4). It is black in colour, and sometimes exhibits magnetic properties; whence its name.

(3) **Clay ironstone** is chiefly carbonate of iron mixed with a variable amount of clay.

All these iron-ores appear to have been chemically deposited on the bottoms of old swamps or lakes, or in fissures and cavities of rocks.

Colouring Matter of Rocks.—(1) Organic matter—the presence of the remains of animals or plants, or of substances derived from them—imparts a gray or black colour to rocks. Ordinary carbon is an absolutely black substance, and it is to its presence in organic matter that this blackening must be attributed.

(2) Iron, in the state of an oxide, imparts a yellow or red tinge to many clays and sandstones; whilst iron, in the state of a carbonate, gives a green, blue, gray, or purple colour.

(3) The action of water percolating through a rock, or the exposure of the rock to the atmosphere, often changes the iron

from the state of an oxide to that of a carbonate, or *vice versa*. Thus the sandstone of East Leicestershire has a rich brown tint at the surface (iron there as an oxide); but when dug at any depth (as in deep wells) it is of a greenish-blue colour (iron present as a carbonate).

(4) Sulphide of iron (FeS) colours rocks a deep-blue, and many limestones are of this colour when got from a considerable depth. But when exposed to the atmosphere these limestones become yellow or brown, the iron being changed into the state of an oxide.

(5) Some sandstones, as those of the Bagshot Beds, are coloured green by silicate of iron.

Petrology and Lithology, or the Study of Rocks.—The science of the study of rocks is somewhat different to the study either of minerals, of plants, or of animals, for rocks have no such definite characters as are possessed by these other materials, and we can only regard them as aggregates of minerals.

The study of rock-masses on a large scale as they occur in the field is termed *Petrology*; but if dealing only with specimens which can be handled the term *Lithology* is employed.

Methods of Studying Rocks:—

I. By handling and examining the specimens with the naked eye, together with the constant use of the pocket lens. It is frequently desirable to break the rock in two directions at right angles to one another, so as to study the structure; for we may have a rock exhibiting parallel lamination when viewed from one direction, but appearing quite different when broken across.

Then rocks obtained from near the surface have been exposed to weathering, and sometimes their appearance is thereby considerably changed; so that it is always desirable to obtain unweathered specimens with fresh surfaces. But at the same time the study of the nature of the weathered rock is often also of value, this being frequently characteristic.

II. The specific gravity of rocks is an important factor in determining their nature; it depends upon—(1) the nature of

the constituent minerals; and (2) on the mode of aggregation of the minerals. It is evident that as the specific gravities of different minerals are different, so the specific gravity of rocks must vary according to the nature and proportions of their constituent minerals. Thus we have quartz and the allied minerals, whose specific gravities vary from 2·3 to 2·6; that of the felspars from 2·6 to 2·8; the olivines, augites, and hornblendes from 2·8 to 3·3; and magnetite, whose specific gravity equals 5·5.

Dark-coloured igneous rocks, which usually contain magnetite, augite, &c., have a high specific gravity; an exception to this rule being obsidian. The density of a rock also depends upon its condition. Rocks may be exactly similar in chemical composition, and yet have very different specific gravities. For example, gabbro, which is a perfectly crystalline rock, has a specific gravity of 2·95, while the specific gravity of dolerite is 2·85, and of the glassy tachylite 2·70. All these three rocks are identical in chemical composition; but it will be observed that the more highly crystalline a rock is, the higher is its specific gravity.

III. It is, however, most desirable to know the chemical composition of the rock, which is of course effected by submitting a specimen to a complete chemical analysis.

IV. The minerals of which the rock consists must also be isolated or parted from one another, so that they can be examined separately. This is effected by first grinding the rock to a coarse powder. A magnet is then passed through the powder, which removes any minerals that contain the magnetic oxide of iron. The remainder of the powder is placed in a heavy liquid, in which the lighter mineral particles float, the heavier minerals, such as augite, &c., sinking to the bottom.

V. Lastly, we must determine the microscopic characters of the rock. To do this we require thin sections of the rock mounted upon glass slides, together with a powerful microscope with which to examine them. An examination of each rock-section through the microscope tells us two things about the rock from which it was cut:—

(1) The nature of the minerals present; the optical characters of each mineral species being different from those of its fellows.

(2) The way in which the minerals are built up to form the rock; in other words, by this microscopical examination we can determine the structure of the rock, as to whether it is perfectly crystalline, or partly so, or altogether glassy.

SECTION D.—DISINTEGRATION AND SOLUTION.

CHAPTER XII.

HOW MINERALS AND ROCKS ARE DECOMPOSED BY NATURAL AGENCIES.

The Breaking up of Minerals and Rocks.—Occasionally great rock masses are suddenly rent by the action of the deep-seated forces which produce earthquakes and volcanoes. And on the coasts the cliffs are frequently battered by detached blocks of rocks (often tons in weight) which are dashed against them by the waves. But these great and conspicuous forces produce not a fraction of the work which is being done every day by other agencies, which, although acting quietly and invisibly, yet act *without ceasing*, and only require sufficient *time* to produce the greatest effects.

The daily alternation of heat and cold splits the surface rocks to pieces. In dry regions like Southern Africa and Western North America there is often a difference of 80° or 100° F. between the temperatures of mid-day and midnight. The rocks cannot bear the continued strain of expansion and contraction resulting from these and similar changes of temperature, and the surface layers scale off daily. Sandstone is in this way caused to crumble into sand, and many sandy deserts—as those of the interior of Australia, the deserts of Arabia, and of Gobi in Asia, &c.—have been thus formed.

Frost acts powerfully in the same direction; rain falls and

fills the crevices of rocks, and if it then freezes, the expansion of the water on turning into ice (10 cubic feet of water become 11 cubic feet of ice) breaks the surface rocks to pieces.

Exposed to the action of air and moisture, all minerals and rocks suffer a *chemical change.* The oxygen of the air unites with and *rusts* them; and the rain-water which percolates through them contains carbonic acid gas and oxygen (dissolved out of the air) which combine with certain of their ingredients, and thus in time cause the hardest rocks to decompose or decay. In the case of granite the carbonic acid combines with the lime, potash, or soda present in the felspar, thus forming carbonates, which, being soluble in water, are carried away, leaving the other insoluble ingredients of the mineral felspar (the silicate of alumina) to form a pure white clay called kaolin. The quartz crystals of the granite, together with most of the mica, are then washed away by rain and form ordinary sand.

Taking the granite crags or 'tors' of Cornwall as an example, the exposed rock will be found decomposed to a depth of many feet (sometimes at a depth of 20 feet below the surface, the granite is so soft that it may be dug with a spade). The extensive deposits of "china-clay" which occur near many of the Cornish granites are really composed of kaolin resulting from the decay of the felspar in the granite; while the glittering sand which forms the beaches of the numerous "coves" or inlets round the adjoining coast is composed of the remaining minerals of the granite—its quartz and its mica.

Granite has been taken as an example, but all other rocks are acted upon in a similar way.

Animals and plants do their share towards denudation. Burrowing animals like rabbits and moles undermine and weaken the ground; even so apparently insignificant a creature as the earth-worm has been shown by Darwin to play an important part in the formation of surface earth or mould.

The wind blows and carries with it particles of sand which cut grooves in the rocks against which they are driven; ice, in the form of glaciers, &c., grinds over the surface rocks and

reduces them to powder; rain beats on the ground; rivers carve out valleys in it; and the sea attacks the coast-lines.

By the combined action of all these agents of denudation, the solid rocks are constantly being disintegrated or broken to pieces, and access is given to those substances—mainly water, with various chemical substances contained in it—which are able first to *dissolve* the minerals which form rocks, and then to carry them away in solution.

Solution of the Minerals composing Rocks.—If time be given, there is probably no substance which is not more or less soluble in pure water. But when water is *hot* (and the water which percolates through the earth's crust gets hotter and hotter as it sinks deeper and deeper) it can dissolve most kinds of matter much better than when it is cold. Again, rain-water contains carbonic acid gas, oxygen, ammonia, &c. (dissolved out of the air by the falling rain), and it obtains more carbonic acid gas from the decaying vegetable matter in the soil. It is calculated that of the water which falls as rain at any given spot, about one-third is evaporated again, about one-third runs over the surface of the ground into the nearest rivulet or river, while the remaining third sinks into the ground, percolates through the rocks, and issues again—it may be at a point very distant from that where it fell—as a spring. But while this subterranean water has been percolating through the rocks, it has been steadily at work, first, in dissolving some of the minerals of which the rocks consist; and secondly, in removing these materials in a state of solution.

Origin of Soils.—In any country it is usual to find the surface of the land formed by a soft layer (not generally exceeding 2 or 3 feet in thickness) of what is called *soil* or mould. Under this comes a somewhat harder layer, the *subsoil*, which may be many feet in thickness; and last of all, beneath the subsoil we come to the true rock. The soil and the subsoil have in most cases been formed out of the solid rock beneath them by the disintegrating agencies we have just described. The soil is commonly of a yellow or brown colour, while the rock from which it is produced may be of quite a different

tint, as blue or gray. The change of colour is due to the oxidation of the iron, of which a small quantity is present in almost all rocks (see fig. 66).

In limestone regions the soil is generally very thin. This is because the carbonate of lime which forms the rock is removed by the water in *solution*, and consequently there is little or no solid matter left to form soil.

Matter in Solution in Rivers.—Since the water which forms rivers has run either over or through the soil, it follows

Fig. 66.—Formation ot subsoil and soil from the solid rock.

that river-water will contain in solution much matter dissolved out of minerals or rocks. This is found to be invariably the case. On an average 100,000 lbs. by weight of river-water contains in *solution* 21 lbs. of mineral matter, of which 11 lbs. is carbonate of lime. The next most abundant substances found dissolved in river-water are sulphate of lime, sodium chloride (common salt), magnesium carbonate and magnesium sulphate, and silica. Taking the Thames as an example, this river is found to carry annually *in solution*, under Kingston bridge, 548,230 tons of mineral matter.

Mineral Springs.—A spring is formed by water which has flowed through the rocks from a higher to a lower level. All

such water contains matter in solution which it has dissolved out of the rocks; but it is only when this dissolved matter is considerable in quantity that the spring is called a *mineral* spring. Very commonly, too, the term is restricted to such springs as contain substances which have a medicinal effect, the places in which they occur being then called "spas". Many springs are *calcareous—i.e.* they contain in solution a large amount of carbonate of lime, a portion of which they deposit on issuing out into the open air. These are often called petrifying springs, and the deposit from them is known as travertine, or calcareous tufa. Other springs contain *silica* in solution, and form a deposit called sinter; still others contain salts of iron, and are known as chalybeate. Ordinary cold spring water is able specially to dissolve the salts of lime and of magnesia; and those are the substances which it most commonly contains.

Of well-known mineral springs in England we may name those at Epsom, which contain much sulphate of magnesia (commonly called "Epsom salts"), Cheltenham, Leamington, Malvern, &c.

Thermal Springs.—Water which has descended to considerable depths below the surface becomes heated. It is then much better able to dissolve the minerals with which it comes in contact; and hence hot or *thermal* springs are not only mineral springs also, but they usually contain a much larger quantity of mineral matter in solution than cold-water springs. The thermal springs of Bath have a temperature of 120° F., and they discharge 385,000 gallons of water daily. Each gallon contains about 168 grains of salts, according to the analysis by Professor J. Attfield on p. 119. Other thermal springs occur at Buxton (82°), Clifton (76°), &c. In volcanic districts, as those of Iceland, New Zealand, &c., thermal springs occur whose temperature is that of boiling water (212°).

The water of artesian wells, which comes from a considerable depth, is usually warm. Thus the water of the artesian well of Grenelle, at Paris, which rises from a depth of 1800 feet, has a temperature of 82° F.

Analysis of Water from the Mineral Springs at Bath.

Carbonate of lime,	7·84
Sulphate of lime,	94·10
Nitrate of lime,	·56
Carbonate of magnesium,	·56
Chloride of magnesium,	15·24
Chloride of sodium,	15·15
Sulphate of sodium,	23·14
Sulphate of potash,	6·70
Nitrate of potash,	1·05
Carbonate of iron,	1·21
Silica,	2·70
Total,	168·25

Substances in Chemical Solution in Rivers, Lakes, and the Sea.—Pure water is a thing which is unknown, except in the laboratory of the chemist. Rain-water dissolves certain gases out of the air while falling through it: and then, aided by these gases, it dissolves portions of the rocks over or through which it runs. It is clear, therefore, that the water of rivers and lakes must contain mineral matter in solution. This may be proved by taking a measured quantity of water out of any river or lake and allowing it to stand till all the *suspended* matter (the sand, mud, &c.) has sunk to the bottom. Now pour off and carefully *evaporate* (as by boiling in a glass vessel) the clear water; a further quantity of solid matter will then be obtained, which will consist of the matter originally held *in solution* by the water. The weight of the suspended matter *added to* that of the matter in solution, will represent the *total* quantity of solid matter originally present in the water. If, further, we know the quantity of water which passes a given point in the river daily, and also the area of the country drained by the river, we can find out the rate at which the river is denuding or lowering its basin, or drainage-area. The Mississippi is doing this at the rate of 1 foot in 6000 years; and the Tay—a more rapid stream—at the rate of 1 foot in 729 years.

Since most lakes are merely expansions of rivers, their water of course contains the same mineral matters in solution.

As all rivers run into the sea, the latter receives daily from their waters many millions of tons of mineral matter; either in suspension or in solution. The suspended matter sooner or later sinks to the bottom of the sea to form, in time, solid beds of rock. Of the matter in solution much is taken out—secreted—by the myriads of shell-fish which inhabit the sea, to form their hard parts or shells, which for the most part are composed of carbonate of lime; other animals—as the sponges—secrete silica, and so on. But the greater part of the mineral matter brought down by the rivers *remains dissolved in the sea-water*. Now we see why the sea is salt; and that, moreover, it must be getting imperceptibly salter every year. The rivers dissolve out of the rocks their mineral ingredients, and carry them into the sea. But the sun only evaporates *pure water*. Therefore the mineral matter is *left behind* in the sea-water. River-water contains common salt, but it does not taste salt, simply because the quantity is so small.

The following chemical analysis of sea-water shows its *principal* constituents, but as a matter of fact such water contains minute quantities (traces) of *every* substance which enters into the composition of the crust of the earth.

One hundred pounds by weight of sea-water contains 3½ lbs. of mineral matter in solution. This mineral matter is composed principally of the following substances:—

Sodium chloride (common salt),	75·8
Magnesium chloride,	9·1
Potassium chloride,	3·7
Calcium sulphate (gypsum),	4·6
Magnesium sulphate (Epsom salts),	5·6
Sodium bromide,	1·2
	100·0

SECTION E.—SNOW AND ICE.

CHAPTER XIII.

GLACIERS AND ICEBERGS: THEIR FORMATION AND ACTION.

How Glaciers are Formed.—In cold regions, as around the poles and also on mountain tops in lower latitudes, all the water which descends from the clouds falls as *snow*. As this snow accumulates, layer upon layer, the lower part becomes squeezed into a mass—half ice, half snow—called in Switzerland *névé* or *firn*, which is drawn slowly down the valleys by the force of gravity, becoming at last a body of pure ice, which moves exactly like the water in a river, except that its downward motion is exceedingly slow.

Fig. 67.—Glacier Table. Large flat stone supported on a pillar of ice; all the surrounding ice having been melted away or evaporated.

The glaciers of the Swiss Alps vary from 500 to 1000 feet in thickness, and in length from 5 to 14 miles. In the Himalayas the glaciers attain to double these dimensions.

Movement of Glaciers.—By driving a row of stakes in a straight line across a glacier at right angles to its course, marks being also placed on the rocks on either side, Agassiz and Forbes proved more than half a century ago that the ice of the Swiss glaciers moves downward about 20 inches per day in summer, and about half as much in winter. Owing to

friction against the rocks, the motion of the ice is slower at the sides and bottom than at the middle and top, exactly as is the case with the water of a river.

Transport of Matter on the Surfaces of Glaciers.—From the steep sides of the rocky valleys down which glaciers usually pass, fragments of rock are continually falling. These detached stones form heaps of rubbish, called *lateral* moraines, along the sides of the glacier; and where the glacier coming down one valley coalesces with that from an adjoining one, the two inner lateral moraines unite to form a *medial* moraine. Most glaciers are crossed by deep cracks called *crevasses*, and down these fissures much of the moraine rubbish falls. The fallen stones then become frozen into the bottom of the glacier, and they grind and groove the rocks beneath the ice, forming an irregular bed of clay and stones *underneath* the glacier, which is called the *ground moraine.* Heat and evaporation lower the icy surface of the glacier daily. But where the surface of the ice is protected from the sun by large stones, it remains unmelted, so that in time these stones are left reared on a pedestal of ice like a table (see fig. 67), all the surrounding ice having been melted away.

Fig. 68.—Mass of Granite (*bloc perché*), resting on a glaciated surface of rock (*roche moutonnée*).

Owing to the great mass of ice of which it consists, a glacier descends far below the snow-line before it is completely melted. All the stones, &c., carried by it are left at its melting point, and there they form a semicircular mound called a *terminal*

moraine. A muddy river runs (often out of an ice cavern) from the point where the ice melts.

By the smoothing and grinding action of the ice the rocks beneath it are worn into rounded humps and hollows. Now, the present glaciers of Switzerland, &c., are not a tenth of the size which they formerly were, as we can trace by the ice-markings on all the rocks around them. The ice-smoothed hummocks of rock—looking like sheeps' backs—are called *roches moutonnées*; while blocks of rock transported by the old glaciers and left perched in singular and often precarious positions on hill-tops and mountain sides, far from the rock-stratum to which they originally belonged, are called *blocs perchés*, or "perched blocks" (see fig. 68).

Fig. 69.—Stony Boulder-clay overlying scratched or striated rock.

Glacial Deposits.—In many countries where glaciers no longer exist, we have evidence of their former presence in the shape of a strong stony clay—called boulder-clay—spread over the surface of the country; and further proof is afforded by the travelled blocks, erratics, or boulders which—still unworn and angular—are found at great distances from their parent crags (see fig. 69).

The photograph of which fig. 70 is a reproduction, represents a huge ice-borne boulder or mass of the rock called andesite, obtained, with other equally conspicuous masses of granite, &c., during the excavations in the public park at Wolverhampton. This Andesite is a volcanic rock consisting

Fig. 70.—Boulder of Lake District Andesite in Wolverhampton Park.

of a glassy matrix or ground-mass, in which are imbedded crystals of orthoclase and plagioclase felspar, with granules of quartz, of hornblende, and of biotite mica. The particular variety of andesite of which the Wolverhampton Park boulder is composed occurs *in situ* in the English Lake District, and has beyond all doubt been conveyed, along with many other boulders, to its present position by ice in some form or other, probably by glacial ice. The district around Wolverhampton is especially rich in ice-borne boulders, the majority of which show the glacial striæ upon their surfaces as fresh as on the day they were produced. Moreover, in the Wolverhampton district we have a remarkable intermingling of typical Welsh boulders with others which were most certainly derived from the Lake District, and with a third group of rocks which have as undoubtedly travelled from the south of Scotland.

Fig. 71.—Separate Boulder (taken out of boulder-clay), showing smoothed and striated surface.

Such deposits of boulder-clay and boulders can be traced in Europe down to the fiftieth, and in North America down to the fortieth parallel of latitude. These deposits are *unstratified*, and the stones included in them are *angular*. They could not therefore have been transported by (liquid) water, and the only agency we can think of as likely to do such work is ice. Boulder-clay is, in fact, the moraine matter of ancient glaciers. It is sometimes hundreds of feet in thickness (see figs. 69 and 71). The long, narrow, and deep lakes which are so characteristic of mountain regions (as in the Alps, the English Lake District, the Scottish Highlands, and North Wales) are believed to have been altogether or in part scooped out by the eroding action of glaciers.

Erosion of Rocks over which Glaciers Flow.—The

power of a glacier to erode or wear away the rocks over which it passes will depend on its weight, on the nature of the valley or channel down which it moves, on the slope of that valley, and on the rock-fragments which fall down the crevasses to be frozen into the bottom of the glacier, there to act as chisels. The steeper and more confined the valley, and the thicker the ice, the more it will erode the subjacent strata. The rivers which issue from the ends of all glaciers that terminate on land are always very muddy, and this mud consists entirely

Fig. 72.—Iceberg breaking off from Glacier.

of matter which has been ground off the rocks by the ice. In Switzerland at the present day the effects produced by glaciers are very visible and very great; but these effects were mostly produced during the Glacial Period (see Chap. XXXIV.), when the glaciers were immensely larger than they are now.

Icebergs and their Work.—In the Arctic and Antarctic Circles the glaciers reach from the mountains right down to the sea, into which many of them extend as tongues of ice. From time to time the buoyancy of the sea-water lifts up and breaks off immense pieces of the protruding seaward end of

the glacier, and these great detached blocks of ice then usually go sailing away toward the equator until they melt. Icebergs vary in length from a few hundred feet to two or three miles. Their height above the water is usually from 50 to 100 feet; but for every foot above water there are 8 or 9 feet below the surface; so that icebergs are often seen stranded in water 1000 feet deep (see fig. 72).

Of the moraine matter which is carried down by the great Arctic and Antarctic glaciers from the land over which they grind, some (the ground moraine) is pushed out where the glaciers enter the sea, and falls at once to the sea-bottom. But the rocks, &c., that are frozen into, or which lie upon the top of the ice, go sailing away with the icebergs, to be gradually dropped as the bergs melt on entering warmer waters.

Icebergs in the North Atlantic often float down to the latitude of 40° before they melt completely away; but in the Southern Ocean they approach several degrees nearer to the equator. All the floors of these seas must be strewed with the matter dropped by the melted ice—stones, mud, &c.—which has thus been carried thousands of miles from the parent rock. Many observers on board ships have recorded the presence of blocks of rock and lines of dirt on the icebergs which they passed.

SECTION F.

CHAPTER XIV.

DENUDING ACTION OF RIVERS.

Origin of Rivers.—As soon as the land is elevated above the waters of the ocean rain begins to fall upon it. The surface of the new land is certain to be more or less uneven, and the rain-drops run together, forming little streams or rivulets, which in turn unite to form rivers. Drawn by the force of gravity, the water in the rivers continually seeks to pass from

a higher to a lower level; it flows down the hollows in the land until finally it enters the sea.

In their course over the land rivers erode or wear away the rocks over which they flow, carrying away the matter partly in solution, partly in suspension.

How the River Mississippi is wearing away the Continent of North America.—Taking the Mississippi as an example, it has been found that the average proportion of sediment (matter in suspension) contained in its water is one part in 1500 by weight—*i.e.* each 1500 tons of the water contains one ton of sand, mud, &c. Now, as we know the quantity of water which annually runs out of the mouth of this river, we can calculate how much suspended solid matter it carries each year into the Gulf of Mexico, and this is found to be 363,000,000 of tons. In addition to this, the river-water contains much matter in *solution* (see p. 15).

Altogether—reckoning both the matter in suspension and that in solution—it has been proved that the Mississippi is eroding or lowering the surface of the country which it drains, at the rate of 1 foot in 6000 years. Now, the average height of that country is 1000 feet. Therefore, should the river continue to do its work as at present, we see that in 6,000,000 years this river will have reduced the greater part of North America to the level of the sea.

Formation of Cañons.—If the rocks are hard, and the incline steep, a river will rapidly cut its way straight down through the strata, and a valley with steep sides, called a "pass", or "gorge", or "ravine", will be formed. In countries where little rain falls, the sides of such ravines may be precipitous, and nearly or quite vertical; such deep narrow cuts are called cañons. The most remarkable cañons in the world are those of the Colorado river, in Western North America (see fig. 4, p. 14), which run for hundreds of miles through a table-land composed of horizontal strata, and which are in places as much as 6000 feet in depth. In this region rain seldom falls, so that there is nothing to wash away the sides of the valley after the river has once cut down its channel;

and as the strata are horizontal, the rocks do not slip down as they would do on one side if the strata were inclined.

Formation of Valleys by Rivers.—Rivers wear away channels in the rocks over which they flow, mainly by the aid

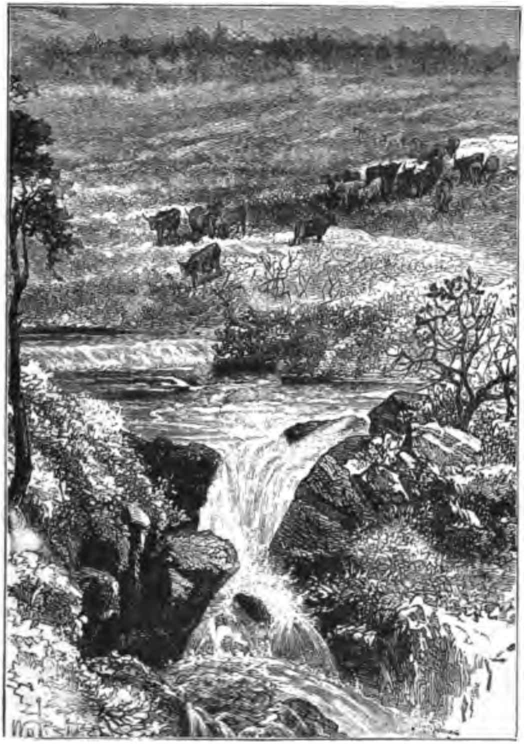


Fig. 73.—Production of River-valley by a Mountain Stream. A River-terrace is seen on one side of the Stream.

of the solid matter—sand, pebbles, &c.—which is carried in, or pushed along by the water, and which is rubbed by the current against the rocks. Not only does a river thus wear away or erode its *bed*, but also its *banks*, under-cutting them so that they fall in from time to time, and thus widen the channel. Rain and frost aid in the formation, and especially in the

widening of the valley, by breaking down the rocks on each side of the river; the detached fragments fall into the stream and are swept away by it. During times of flood the water extends over the ground on either side of the river-channel. Often it then cuts a new channel, and this is repeated time after time, the river-bed thus moving across the valley, flowing first on one side and then on the other, but all the time steadily wearing down the rocks (see fig. 73).

River-terraces.—As rivers cut their way down valleys with gently sloping sides they leave behind them accumulations of gravel, sand, and loam, which form flat steps or terraces running in lines along the sides of the valleys. Each terrace marks a time when the river ran level with it. It is often difficult to believe that the insignificant stream of water which we now see meandering along the bottom of a valley which is perhaps many miles in width, and hundreds, or even thousands of feet in depth, can have been the agent by which the whole of the rocks that once filled that valley have been eroded and removed. But we must remember that given *time* enough, a small force is capable of performing a great work; and a great length of time can usually be allowed for all geological operations. In old river-terraces now lying from 60 to 100 feet above the rivers Seine and Somme in France, and the Thames, Ouse, &c., in England, flint implements—the work of palæolithic man—have been found; a fact which goes to prove that man has been for a very long time an inhabitant of the earth.

What becomes of the Material transported by Rivers?—A few rivers empty themselves into inland seas (which they gradually fill up), a few lose themselves in the sands of desert regions, but the great majority pour their water—and all that it contains—into the sea. If a swift current sweeps *across* the mouth of the river, all its suspended matter—its pebbles, sand, and mud—are carried out to sea and dropped; the pebbles first, then the sand, and lastly the mud. This is now the case with the rivers Amazon and Orinoco; and water discoloured by mud has been observed at sea at a distance of 300 miles from the mouth of the former river.

In the case of most of our English rivers, as the Thames, Severn, &c., the seas into which they flow are traversed by strong tides and conflicting currents. The result is that the sediment is deposited in banks and shoals over the adjacent sea-beds. Such banks are continually shifting, and they are a constant danger to the navigation of the estuary of the Thames and of the Bristol Channel.

Formation of Bars and Deltas.—If the estuary of a river is fairly deep, the motion of the river-water is rather suddenly arrested by its contact with the water of the sea. The river sediment then at once falls to the bottom, and forms a curved bank or *bar* stretching right across the mouth of the river. Such bars are a great hindrance to navigation, as they can only be crossed by vessels of any size at high tide, even if then.

But where a river enters a tranquil and shallow sea—one in which the tides and currents are insignificant—its sediment sinks in the very mouth of the river, and in time fills it up. The river is then compelled to divide, and to flow in a Y form round either side of the obstruction. This process is repeated again and again; the river pushes its mouth out farther and farther, its sediment forming an expanse of low flat land, which is known as a *delta*, from its resemblance in shape to the Greek letter Δ (delta). The delta of the river Po is extending seaward at the rate of 300 feet annually; and the thickness of its deposit is found (by Artesian wells sunk in Venice) to be 566 feet. This river-deposit must have been laid down upon a gradually subsiding area for it to have attained so great a thickness. On this delta stands the town of Adria, which was a seaport in Roman times, and gave its name to the Adriatic Sea, from which it is now as much as twenty miles distant.

The delta of the Mississippi has an area exceeding 12,000 square miles; while that of the Ganges exceeds 50,000 miles. The delta of the Nile commences at Cairo, which is now 85 miles from the coast; its area is 12,000 square miles (see fig. 11).

SECTION G.

CHAPTER XV.

THE SEA AS A GEOLOGICAL AGENT.

Marine Denudation.—The action of the sea has been compared to that of a horizontal saw, cutting into the land. Although the sea has doubtless a powerful action in eroding, denuding, and wearing away the land, yet its effect is not nearly so great as that of rain in this respect. The reason is obvious—the rain acts over the entire surface of the land; the sea only at the junction of the land with the water. The sea can only act mechanically upon the solid crust of the earth where it has power to move matter, such as sand or mud. Now, below two hundred feet in depth this power is not worth mentioning. In storms the waves are flung against the cliffs; but here again they can do little if any damage at a greater height than 200 feet. We may say, then, that the erosive effect of the sea is practically felt only between a depth of 200 feet below low-water, and 200 feet above high-water. The photograph of a breaking wave (fig. 7) was taken at Pen-y-chain, a bold headland consisting of igneous rocks traversing Ordovician shales which project into Cardigan Bay, about half-way between Criccieth and Pwllheli. Here—as everywhere along every coast-line—we find the sea acting as a "horizontal saw". Every wave weakens the rocks against which it dashes; and in tempests the power of the waves is prodigious. It is chiefly by its mechanical action that the sea performs its denuding and erosive work. This can only take place where the water is in motion, and, other things being equal, the erosion of the coast will be greatest where the motion of the water is strongest. Mr. Stevenson—the lighthouse engineer—records that on the west coast of Scotland stones exceeding nine tons in weight were rolled over and over by the waves breaking on the tops of cliffs exceeding fifty feet in height, and many similar instances are on record.

Breakers and Landslips.—As the waves roll in towards a coast they reach shallow water and their motion is arrested. The top of the wave then curls over and foams, and the water dashes itself or *breaks* upon the shore; hence such waves are called *breakers*. The force of the mass of water in each wave is considerable, but the water is greatly aided in its attack upon the land by the pebbles and debris which lie on every beach and at the foot of every sea-cliff. These are raised by the water and thrown against the rocks, which they steadily batter down.

Where the rocks are very hard and precipitous, as on the west coasts of Ireland and Scotland, the sea often wears out a series of hollows or sea-caves in the cliffs. Presently the tops of these caves fall in, and so the sea advances.

In certain regions, as on the east side of the Isle of Wight and on the Dorset coast, the strata *slope towards the sea*, and there is a bed of clay below, with limestone (chalk) or sandstone above. Rain-water sinks through the porous limestone and courses along the junction between it and the clay beneath, thus lessening the adhesion of the one stratum for the other. At last a great mass of the limestone (sometimes many acres in extent) slips or slides forward over the clay and falls into the sea, or upon the beach below, where it is speedily broken up and removed by the waves.

Along the Dorset coast, near Lyme Regis, the Chalk and the Upper Greensand rest upon Rhaetic and Liassic clays, and dip slightly towards the sea, while numerous springs issue at the junction of the sands above with the clays below. In 1839 about 22 acres of land here slipped down towards the sea, leaving a chasm 1000 yards in length by 300 in breadth.

It is noteworthy that the cliffs along our coasts almost always *slope back* considerably from the sea.

This shows that those forces of denudation—principally rain and frost—which act upon the *tops* of the cliffs, do considerably more work than the sea, which cuts only into the *bases* or bottoms.

Rounding of Pebbles.—The fragments freshly detached from rocks by the action of the sea, or by frost, &c., are

always *angular;* they have sides more or less *flat,* and edges more or less sharp. If these angular stones get into rivers they are continually knocked by the stream against one another, their angles are worn off, and they become rounded—usually oval—pebbles. The same things happen to the rock-fragments which fall on beaches, or directly into the sea. The waves, set in motion by the wind, dash the stony blocks against one another and upon the shore; they soon become *sub-angular,* and finally *rounded,* and they also get *smaller* and *smaller,* until at last, according to the nature of the rock, they become either grains of sand or flakes of mud.

Formation of Shingle-beaches.—"Shingle" is a name applied to any collection of loose stones. Where marine currents or strong tides run parallel to a coast-line, and where there are also cliffs or promontories of hard yet jointed rocks, the angular fragments of rock which are detached by the united action of the forces of denudation are rolled along, rounded, and arranged in lines, beaches, or banks. A good example is the Chesil Beach on the Dorset coast, which extends for sixteen miles west of Portland Bill, the spot whence its pebbles are derived. These pebbles vary regularly in size, from four inches in diameter near Portland, to mere grains of sand at Burton Bradstock, their westward terminus. In the early part of this century this fact was an advantage to the Channel smugglers; for by the size of the stones they could tell, on the darkest nights, exactly upon what part of this beach they had run. In Scotland the Moray Firth is noted for its shingle-beaches; and so is Lake Superior in North America. The Bunter Pebble-bed of the Trias is an old shingle-beach or shoal.

Sand-dunes.—Deposits of loose sand form a flat narrow expanse along the margins of many seas and lakes. When the wind blows pretty regularly in one direction—inland—over such stretches of sand, and when the sun is hot enough to thoroughly *dry* such sand as the tide goes down (so that it can be easily moved, grain by grain, by the wind), the effect is to form low hills or *dunes* of sand parallel to the coast. If nothing is done to check its advance, the dry sand is steadily

blown, moved, and rolled inland for a distance, it may be, of several miles, destroying the vegetation and rendering the land covered by it worthless. Of late years, however, such encroachments of sand have been checked in most countries by planting the sand-dunes with pine-trees, and by encouraging the growth of such plants as the sand-carex or "marram", a kind of sedge whose long rootlets bind the sand together and keep it damp.

Sand-dunes fringe the coasts of Norfolk and Lincolnshire, reaching there a height of 50 or 60 feet; they are also found on the eastern and northern coasts of France, and extend thence along the shores of Holland and Denmark. Along the Bay of Biscay the sand travels inland at the rate of 16 feet per annum; in Denmark the rate varies from 3 to 24 feet.

Similar slow-moving ridges or hills of sand occur in most desert regions, as the Sahara, Arabia, interior of Australia, &c.

Formation of Bays and Headlands.—Just as rain and rivers, frost and ice, act *unequally* upon the rocks which compose the surface of the land, wearing away the *softer* strata to form valleys and leaving the *harder* beds to stand up as ridges and hills, so do the waters of the oceans act *unequally* upon the hard and the soft rocks of coast-lines. Of course the waves require time, and a long time, to do their work; but the present indentations of our coast-lines are the result, mainly, of marine denudation carried on for many thousands of years.

If we follow the outcrop of each stratum or rock-bed across a country until it terminates in the sea, we shall find the softer beds—as shale, clay, &c.—forming the low receding shores of bays and gulfs; while the masses of harder rocks, such as sandstones, limestones, &c., together with most of the igneous and metamorphic rocks, form capes, headlands, or promontories. In the same way the islands which lie near any coast are usually bosses of hard rock, which have withstood the wear and tear of the sea better than the surrounding softer strata; as, for example, St. Michael's Mount, off the Cornish coast, which is composed of granite; while the surrounding strata (which have been largely washed away) are of slate.

Flamborough Head, with the North and South Forelands, and Beachy Head, are masses of hard chalk. Portland Bill is composed of hard Oolitic limestone. Torbay has been worn out in the soft Triassic marls which there lie between Berry Head and Hope's Nose—two headlands of hard Devonian limestone. The promontory of Cornwall owes its existence to the hardness of its rocks, the great boss of granite at Penzance boldly withstanding the Atlantic waves; and so we might go on all round our coasts.

Fjords.—In Norway there are a great number of deep narrow valleys running down into the sea, and in some cases they are for the greater part of their course filled with sea-water. They are termed lochs, firths, or fjords. The entrance from the sea is shallow, but the inner part of the fjord is deep, and the cliffs on each side are high, and pass down vertically into the water. These fjords are the seaward continuations of land valleys which have become partly submerged, owing to the subsidence of the land. The sea is utterly incapable of cutting them out, for below its level the sea cannot denude hard rocks; it is only between the tidal marks that the sea can act as a really powerful denuding agent. We can only account for the existence of such fjords by (1) their formation as land valleys by the denuding away of softer material by glaciers and other sub-aerial agents; and (2) the subsequent subsidence of the country in part below the sea-level.

Plain of Marine Denudation.—The photograph (fig. 74) shows a "plain of marine denudation", now in the course of production on the Yorkshire coast, near Whitby. This level surface, at or about the sea-level, we may regard as the final result of the denuding forces. With the production of such a plain, the sea has really had little to do as compared with the sub-aerial agents of denudation. It may be defined as that base-level to which a mass of land has been reduced chiefly by sub-aerial forces; the line below which further erosion becomes impossible, because the solid rocks are now protected by being covered by the sea. The final wearing down and smoothing off was undoubtedly done by the marine waves and currents,

Fig. 74.—Sea-coast near Whitby. The cliffs consist of the Lias capped by Oolite. A portion of a "plain of marine denudation" forms the foreground.

and the limit of the plain usually corresponds with the limit of low-tide or of wave-action. The horizontal belt of sea-beach which almost everywhere encircles our island will, unless elevated by subterranean forces, form part of the "plain of marine denudation" which now lies below the adjacent sea-water.

Formation of Stratified Rocks on the Floors of Seas.—By far the greater part of the rocks which now compose what we call the "land" has been originally formed or deposited as soft incoherent material upon the floors of seas.

Sea-water contains *in solution* almost every known mineral; and the animals which live in the sea—the foraminifera, the shells, fishes, &c.—absorb or secrete out of the water as much of the carbonate of lime, silica, &c., as they need to form their hard parts or skeletons. When these animals die, their hard parts lie upon the sea-floor and may become embedded there as *fossils*. Sometimes the shells, corals, &c., grow, or are swept together by currents, to such an extent that they form by themselves a distinct stratum or layer, as in the case of the White Chalk, and of certain other limestone strata, which are therefore termed *organically-formed* rocks.

But sea-water also contains much matter *in suspension*—mud, sand, &c., brought down by rivers or washed off coast-lines. Although this suspended material may be carried for hundreds of miles by currents, it is ultimately all drawn to the sea-bottom by the force of gravity. Pebble-beds are formed along coast-lines; the sand sinks next, a little farther out; while the fine mud is deposited at a point still more remote from the land. Farther out still, in the clear water, a stratum composed of the remains of shells, foraminifers, or corals is probably at the same time being formed. Thus at the present moment strata are being formed at the bottom of every sea, just as they have continued to be formed ever since there was any sea and any land; the order of occurrence of the deposits as we recede from the coast-line being usually (1) pebbles and shingle; (2) sand; (3) mud or clay; (4) limestone.

Consolidation of Strata.—Each bed or stratum of the ordinary aqueous rocks—sand, mud, &c.—is laid down on the

sea-floor in a more or less loose, soft, and incoherent state. But by subsequent changes these strata become consolidated and hardened, so that we call them sandstone, shale, &c.

The first agent in this work of consolidation of the rocks is *pressure.* The deposition of matter on the sea-floor is more or less *continuous*, and a thickness of thousands of feet of sand, clay, &c., may be deposited in the same place. Then the lower and middle parts of this mass are crushed and squeezed together by the weight of all the rocks above them; and this crushing is alone sufficient to make the loose grains and flakes into a solid coherent mass. We have an example of this in the manufacture of black-lead pencils. The graphite or black-lead is powdered very finely, and then by the action of a hydraulic press the powder is pressed into solid sticks.

Chemical changes, too, must take place in the sedimentary matter when it is thus pressed together in a moist and heated state. We know how plaster of Paris *sets* or hardens when mixed with water, and similar changes take place in the rocks.

Water percolating through the rock dissolves any shells which may be present, and then redeposits the carbonate of lime (of which the shells were composed) as a crust or film round every grain of sand or flake of mud, and this carbonate of lime then acts as a *cement*, *binding* the materials of the stratum together. Silica, and oxide of iron, together with many other substances, are also carried in solution by the water and deposited in a similar way to the carbonate of lime and with the same result.

Internal Heat of the Earth.—The interior of the earth is very hot; and as the strata are pressed down by the weight of the matter deposited upon them, they come under the influence of this internal heat, and by it are more or less baked and hardened. By this internal heat, *combined* with pressure, the rocks are often so changed or *metamorphosed* as to be hardly recognizable, limestone being converted into marble, shale into slate, &c.

In these ways, by pressure, by chemical change, by the introduction of cementing matters, and by heat (and especially by

a *combination* of some or all of these agencies), all the sedimentary strata which form the crust of the earth have been consolidated and hardened. The intensely hard rocks which ring under our hammers were once as soft as the sand and mud which yield under our feet as we walk along the sea-shore.

CHAPTER XVI.

Fossils: their Nature and Preservation.

What is a Fossil?—The word *fossil* is derived from the Latin *fossus*—that which has been *dug up*—and is applied to any remains or traces of animals or plants which have by natural causes been embedded in the crust of the earth. Thus a tree-trunk which has been swept away by some recent flood and embedded in a swamp is as truly a fossil as the bones of the great reptiles we dig out of the cliffs at Lyme Regis. We have, too, fossil worm-burrows and fossil footprints; and sometimes the word is applied, though not quite correctly, to the ripple-marks and rain-pittings which are to be seen in even the most ancient rocks.

How Fossils have been Preserved in and upon the Land.—When land animals or plants die their bodies generally lie upon the surface and decay until no trace of them is left. This is the reason why such remains are very scarce in the stratified rocks. Occasionally, however, the bones, shells, leaves, &c., of the terrestrial fauna and flora are swept away by floods or are blown into the sea or into lakes, and there become buried and fossilized.

In caverns, too, we often find animal remains preserved by their having been covered over and sealed up by a deposit of stalagmite. Such bones may either be those of animals which inhabited the cave or of other animals upon which they preyed; or they may have been carried into the cave by a stream of water. Such "bone-caverns" are common in the

limestone rocks of England, Germany, &c.; and the fossil human bones and flint implements (the first traces of man) also found in many of these caves all belong to the latest or Pleistocene Period.

The bones of many large animals, such as (in Europe) deer, elks, and oxen, and in North America the mastodon, &c., have been found in old bogs and peat-mosses. These animals, when wandering over the country, became entrapped or "bogged" in such treacherous places, and were unable to extricate themselves. The peat-mosses of Ireland have yielded many perfect skeletons of that magnificent extinct deer—the Great Irish Elk (*Megaceros Hibernicus*).

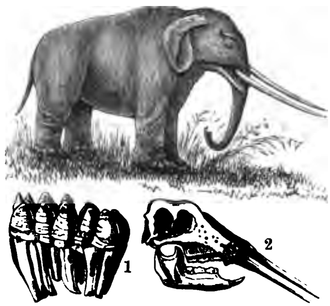


Fig. 75.—Mastodon restored.

1. Molar tooth, weighing 17 lbs. 2. Skull of Mastodon.

The alluvium, or alluvial deposits of mud, sand, &c., formed by rivers at points along their course, and deposited especially during times of flood and near the mouths of the streams, also frequently contain the bones of large land animals which were (probably) drowned and the carcasses washed away and embedded in the mud (now called "brick-earth") during Pleistocene times. The brick-pits of Ilford, in Essex, have yielded many tusks and skulls of the mammoth and wild ox, some of which are preserved in the British Natural History Museum at South Kensington.

Along the coasts of many countries, especially of Denmark, low mounds (3 to 10 ft. high, and sometimes 1000 ft. long) composed of common edible shells (such as mussels, cockles, and oysters) are found, in which bones abound, with a few human tools of stone. These shell-mounds (or "kitchen-middens" as they are called) are the refuse-heaps left by prehistoric tribes of savages who spent much of their time on the sea-shore, where they found it easy to obtain food.

Even volcanic ejections sometimes incase and preserve traces of the life of the regions surrounding the volcano. For many years the work of digging out the town of Pompeii, near Naples (buried under ashes ejected from Vesuvius during the famous eruption of A.D. 79), has been persevered with, and a great number of articles of the highest interest have been recovered. In some cases hollows in the ash-beds at Pompeii turned out to be *moulds* of the bodies of persons who had perished in trying to escape. By pouring liquid plaster of Paris into such moulds (the plaster soon hardening or "setting") perfect *casts* were obtained of the bodies of those persons.

Volcanic ashes frequently fall into the sea, so that we sometimes find marine shells preserved in them. A brachiopod shell —*Orthis flabellulum*—is common in the calcareous ashes (of Ordovician age) which form the very top of Snowdon, now 3571 feet above the sea.

The blown sand which we have described under the name of 'Sand-dunes' (p. 134) rolls over and entombs everything which is unable to get out of its way. Plants, land-shells, &c., are often buried in it; and in North Africa even cities and temples have been slowly overwhelmed in this way.

How Fossils are Preserved.—To begin with, we can scarcely expect more than the *hard* parts of the animal or plant to be preserved. The internal bony skeleton of vertebrates is mainly composed of phosphate of lime; fishes and saurians are often covered with hard bony plates and scales; shells and corals are chiefly composed of carbonate of lime; and the trunks, branches, hard fruits, and dry tough leaves of plants consist of cellulose. These substances are all hard and more or less lasting, and they are the substances we most frequently find in a fossil state, all the softer parts of the animals and plants having decayed and perished.

We may (1) find the object *preserved exactly as it was in life*, as in the case of the Siberian mammoths, whose carcasses, embedded in the perpetually frozen soil, are occasionally revealed by the fall of coast and river cliffs. In such cases the wolves make a meal of the flesh—although the animal died

certainly thousands of years ago—and the tusks, hair, &c., are to be seen in certain of the Russian museums.

(2) The soft parts may have decayed and been removed by water, &c., while the hard parts remain. In the beautiful ammonites, which are so common in the clays of the Oolite Formation, the shell is often so perfect as to retain its pearly lustre; but the interior (once filled by the soft flesh of the animal) is invariably full of clay.

(3) All rocks are more or less porous, sandstone especially so; and the water percolating through the porous rock slowly dissolves and removes the whole of the substance of the fossil, first the softer and then the harder parts. But the surrounding mineral matter—the sand, clay, &c., which was deposited closely around the fossil—still preserves the exact shape and markings of the outside of the fossil. We have then left only a stony *mould* of the animal or plant. By softening gutta-percha in warm water and pressing it upon the mould a good impression of the original fossil can often be secured.

(4) The interior of the mould formed in the rocks, as described in the last paragraph, may remain as a cavity, but more usually it becomes filled up with mineral matter—very commonly either carbonate of lime, or silica, or pyrites—left by the percolation of water. This deposited matter takes the exact shape of the original fossil; and is called a *cast.*

(5) The substance of the fossil may be removed, molecule by molecule, and each organic molecule replaced by an inorganic molecule, the change being generally effected by the agency of water. This is the true process of *petrifaction.* The change is often effected so gradually and thoroughly that the most minute structure of the fossil is preserved. Silicified wood is a good example of this. The cellulose of the woody tissue has been removed by percolating water, and for every molecule of cellulose so taken away a molecule of silica has been deposited from solution in the water in the same place.

Preservation of Shells, &c., in Marine, Lacustrine, and Estuarine Deposits.—The remains of animals or plants which have died in the water, or which have been washed into

seas, rivers, or lakes by heavy rains or floods, are by far the most common of all the objects found in a fossil state. When a fish, &c., dies, its body sinks to the floor of the sea, is then often rolled about by currents, and its soft parts rapidly decay and disappear. Its hard parts, however, may become buried in the sediment, and then it stands a fair chance of becoming a fossil. But for one animal or plant whose remains have been entombed and preserved in this way during past ages, millions have decayed completely, have been crushed, rolled, and ground to atoms, and have left no trace of their existence. Of the life of the earth in times gone by probably not one species in a thousand has been preserved as a fossil; and of those which have been so preserved we are probably not yet acquainted with more than the tenth part. Hence the *imperfection of the geological record*; and hence, too, the impossibility of tracing the exact steps by which the life of the earth has been spread and modified.

Fig. 76.—Slab of Shale with Impression of a Fossil Fern.

Marine fossils will be most rapidly covered up or imbedded in localities near the coast, especially near the mouths of great rivers where much sediment is swept out to sea.

In estuaries—as the wide mouths of tidal rivers are called—the deposit of sand, mud, &c., is also rapid, and the thousand objects swept down daily by the river—the carcasses of dead animals, trunks and leaves of trees, insects (which have been blown into the river), land-shells, &c.—will then all rapidly sink to the bottom and be covered up.

In lacustrine or lake deposits we get similar material brought in by rivers, together with the fresh-water fishes, shells, &c., which usually inhabit lakes, and the leaves, &c., of trees and plants which grow along the margins (see fig. 76).

Pseudo-fossils.—We sometimes find in rocks structures which bear a greater or less *resemblance* to animate objects, or

at least to objects which once possessed life, but which are in truth only inorganic substances *simulating* these objects. To these the term "pseudo-fossils" or *false-fossils* has been applied. Among these pseudo-fossils we may include the fern-like markings found upon the surfaces—usually on the joint-planes or bedding-planes—of many rocks. These "dendrites" (as they may be called) consist of matter (often the oxides of manganese and iron) contained in solution in water, and left behind by the water as it percolated through or along the rocks. The beautiful markings seen within the so-called "moss-agates" are of similar nature, never having been either a "moss" or any other kind of vegetable. The exquisite outlines often produced by frost upon our window-panes are of a similar origin. In the Lias shales the crystals of selenite sometimes group themselves together into curious flower and leaf-like markings: (see fig. 77).

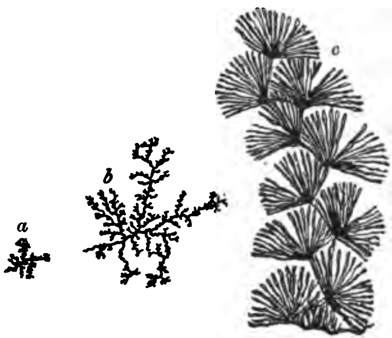


Fig. 77.—Pseudo-fossils.

Dendrites on surfaces of flint hatchets in the drift of St. Acheul, near Amiens. *a*, natural size; *b*, magnified; *c*, *Oldhamia antiqua*, Forbes, Wicklow, Ireland.

It is not at all improbable that both the famous *Eozoon Canadense* of the Archæan rocks of Canada, and the *Oldhamia* found in Cambrian strata, at Wicklow in Ireland, may be of the nature of pseudo-fossils. The matter is perhaps as yet hardly finally settled, but Professor Sollas considers that the *Oldhamia* (thought for many years to be either a plant or the remains of some lowly animal) is only a peculiar wrinkling due to the contraction of a fine mud while it was drying; while Professors King and Rowney have shown the probability that the so-called "organic structure" of *Eozoon* is really due to an infiltration of one mineral into another—serpentine into calcite.

Then, in districts where there are mineral springs containing

much carbonate of lime, we often get natural objects—such as twigs, birds' nests, &c.—coated with an *incrustation* of the carbonate of lime. In these cases the matter forming the object itself—the leaf, a twig, &c.—is decayed and carried away by the water. Such incrustations are not true fossils, and they may be considered as a link between the true fossils and the pseudo-fossils; the latter consisting of objects which have not, and never had, anything to do with living organisms, the resemblance which they present to the latter being purely accidental.

Many flints offer good examples of pseudo-fossils, for the forms which flints assume are so many, so irregular, and so varied that it only needs a little imagination to be able to select flints which bear some superficial resemblance to a large number of objects, such as "fingers" and "toes", &c. &c. Some stones when broken open give outlines which sometimes curiously mimic those of the human face—another example of a "pseudo-fossil".

Derived Fossils.—We have insisted on the fact that "strata are characterized by their fossil remains"; and that by finding in a quarry a trilobite, or a graptolite, or an ammonite, for example, it is possible to tell almost exactly the position which the rocks of that quarry occupy in the great geological series. But we must now state, as a necessary condition to this exactitude, that the species of fossils must have been "born and bred" in the rock in which we find them. For it not uncommonly happens that fossils—*derived fossils* they are then termed—are found in rocks of much later age than that which first inclosed their remains and gave them burial.

The Bunter Conglomerate of the Trias is formed of pebbles of hard palæozoic rocks, and these pebbles contain quite an assemblage of fossils which lived during the earlier stages of the earth's history—millions of years before the Triassic epoch. These old rocks formed part of the coasts of the shallow sea or strait in which the Bunter Conglomerate was formed, and the fossils are there simply as portions of these old rocks. They are *derived fossils*—they are not "at home" in the Trias.

The Lower Greensand of the south-east of England contains many derived fossils from the Jurassic strata.

Near Cambridge the so-called "Cambridge Greensand" contains great numbers of Gault fossils. But it is now known that this "Cambridge Greensand" is really a bed forming the base of the Chalk Marl, and that it rests unconformably upon the Gault, from which so many of its fossils have been *derived.*

But it is in connection with the "Crags" of the Eastern Counties that derived fossils have caused the most difficulties. Here we have a succession of shelly strata differing—though not very greatly—in geological age, and resting directly upon one another. Here in each "Crag" we have—(1) a collection of shells proper to the rock itself, consisting of species which lived and died, and were buried up and preserved during the actual accumulation of the rock itself; and (2) another set of shells which were simply washed out of the low cliffs forming the coasts of shallow seas in which the shells of set (1) were then living. The two sets of shells were mixed up by the waves of the sea, and entombed side by side in the sands. Yet the careful researches of geologists have enabled them to separate the one set from the other, and to say these (set No. 1) are proper to the rock, and these (set No. 2) are derived fossils.

Lastly, in the Drift which covers so much of the British Isles the numerous fossils are nearly all *derivative.* As the glaciers rubbed over the country they broke up, removed, and finally left, huddled together, rocks (often inclosing fossils) of the most diverse geological ages. Thus in a sand-pit in the Drift of the Midland Counties we may find a Liassic ammonite side by side with a Silurian trilobite, while a Coal-measure plant perhaps lies "cheek by jowl" with a tusk of the mammoth.

Tests for Derived Fossils.—We can usually distinguish derived from contemporaneous fossils by applying one or more of the three following tests:—(1) Derived fossils are more or less *water-worn,* and therefore rounded; for during their passage from their original bed to their new home (and this transference may have happened more than once) they were

rolled and rolled so that their angles were worn off. (2) The matrix or lump of rock in which a derived fossil is imbedded is usually *different* from that of the stratum in which the fossil is now inclosed. (3) Derived fossils are commonly in a different and more *advanced state of mineralization* than that of the fossils or of the rock in which they now occur.

SECTION H.--INTERNAL HEAT: VOLCANOES; EARTHQUAKES AND OTHER MOVEMENTS OF THE EARTH'S CRUST.

CHAPTER XVII.

THE EARTH-CRUST STILL HOT AND IN MOTION—CORAL-REEFS.

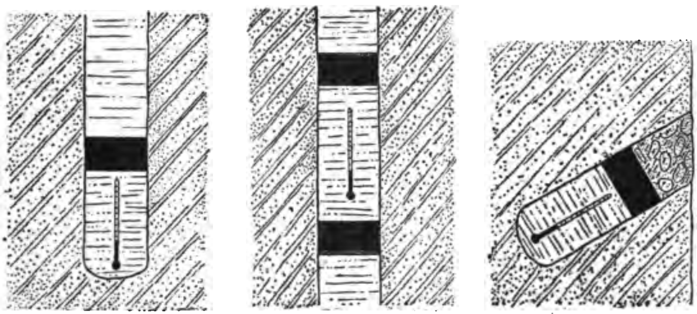
Evidence of the Existence of so-called Central Heat in the Earth.—The nebular hypothesis (which is that most generally accepted) states that our earth, and the sun, moon, and planets, with all the other members of the solar system, once formed a mighty rotating cloud or expansion of intensely hot gaseous and meteoric matter. As this rotating mass cooled it contracted, and threw off ring after ring, the matter in each ring running together and uniting to form a planet. The central part of this old nebula still remains as a white-hot, partly liquid, partly gaseous ball, which we call the sun.

At some very remote period—probably more than 100,000,000 years ago, though it is impossible to reckon geological time by *years*—the surface of the planet upon which we live—our earth—had cooled down sufficiently to allow a *solid crust* to be formed on it, and it has gone on cooling ever since. If this theory be correct, the interior of the earth should still be *hotter* than the exterior; and all observations prove this to be the case. The facts which demonstrate the existence of this "central heat" may be briefly stated as follows:—

(1) In active volcanoes the matter which is ejected from the crater—the lava, gases, &c.—comes from the interior of the earth, from depths of it may be 1, 5, or even 30 miles; and this ejected matter is invariably very hot. It must, therefore, come from a hot place.

(2) Hot or thermal springs, which occur in many parts of the earth, consist of water which has percolated down to a considerable depth, has there been heated, and has then been forced to rise to the surface again.

(3) Observations made in the deep mines or bore-holes, of which so many have been put down of recent years to depths



a b c

Fig. 78.—Thermometers in hollows or water chambers in rocks: *a*, at bottom of bore-hole; *b*, mid-way in bore hole; *c*, in cavity at side of shaft. The black bands represent plugs, which prevent the circulation of water.

of 2000, or even 4000 feet, prove that there is a steady increase of temperature as we go downwards; the average increase being 1° Fahrenheit for every 50 feet. These observations are made by embedding self-registering thermometers in the rock at every 10, 20, or 50 feet, leaving them there for a few days, and then taking them out and noting the highest temperature which they have marked. Down to 100 feet below the surface the temperature of the rocks varies slightly with the season of the year; but below this point the rate of increase is on the average that which has been stated above, viz., 1° for every 50 feet (see fig. 78).

Probable Thickness of the Earth's Crust.—If the heat continues to increase steadily at the rate of 1 degree for every 50 feet below the surface of the earth, we shall soon arrive at a point where the temperature must be enormous; enough to melt—*at the surface*—all known substances. Thus at a depth of 50 miles, if the increase continues as stated, the heat must exceed 4000° F., which would melt even platinum, one of the most refractory or difficult to melt of all the metals.

(1) **Thin-Crust Theory.**—For this reason it was formerly thought that the earth had a solid crust, or skin, or exterior, not more than about 25 miles in thickness, and that all the rest of the interior of the earth was filled with matter in a liquid state. But if this were the case, *tides* would be produced in this liquid—just as they are in the ocean—by the attraction of the sun and moon. Now Lord Kelvin has shown mathematically that to prevent such tides from breaking through and reaching the surface, the crust of the earth must be *at least* 2000 miles thick.

(2) The Rev. Osmond Fisher has ably supported the idea that all the central part or *nucleus* of the earth is solid, as well as the crust; but that *between* the two there is a space filled with *liquid* matter.

(3) By another theory which has been advanced, the earth is solid as a whole, but here and there, near the surface, there are *cavities* filled with liquid or even with gaseous matter.

(4) **The Earth Solid to the Centre.**—Lastly, the idea or theory which has now most supporters is, that the earth is *solid throughout.* It is urged that in all probability the heat does not go on increasing at the rate we have named (1 degree F. for every 50 feet); and further, that although the heat at great depths may be very great, yet the *pressure* there (caused by the weight of all the rocks above) must be very great also; great enough to counterbalance the melting-power of the heat. For, from experiments which have been tried at the surface, we know that the greater the pressure to which any substance is subjected, the more heat is required to melt it.

The phenomena of volcanoes, &c., can be well explained

under this last theory by remembering that when parts of the earth are upheaved by the steady contraction of the earth-crust (see p. 153) the pressure is altogether or in part *taken off* from the rocks underneath that part. When thus freed from the superincumbent pressure, these rocks at once liquefy; and, by the aid of steam, are then often forced up through fissures to the surface, where they appear as lava streams.

Thus the probable thickness of the earth's crust is 4000 miles; which is the distance from any point on the surface right to the centre of the earth.

Corals and Coral Reefs.

Nature of the Coral Polyp.—Corals are animals of a low degree of organization which belong to the class *Actinozoa*, of the sub-kingdom Cœlenterata (see p. 184). They are often spoken of as 'insects', but this is wholly incorrect. Those who wish a familiar name for them may call them 'polyps', a term which refers to the circles of rays or tentacles with which they are furnished. For our purpose corals may be divided into two groups. First, those which live separately or detached, and which are found on the floors of seas at all depths down to 3000 fathoms; and secondly, those which live together, with, and upon one another, thus forming in time large stony masses or 'reefs'. This second class of corals cannot live at a depth exceeding 20 fathoms. The species belonging to this class also require *clear* water of a temperature not colder than 68° F. For these reasons the living reef-building corals occur only in the warm waters of tropical seas. They construct their hard part or skeleton out of carbonate of lime, which they secrete or absorb out of the sea-surf which continually dashes upon the coral-reefs (see fig. 79).

Fig. 79. — Brain-coral (*Meandrina cerebriformis*). This is one of the compound or reef-building corals.

Nature and Classification of Coral-reefs.—A great chain of coral isles, about 300 in number, stretches across the

Pacific from the Caroline Archipelago to the Low Archipelago, a distance of 7000 miles; another band of similar islets extends across the Indian Ocean from India to Madagascar, of which the Red Sea reefs may be considered to be a branch; the third division is found on the west side of the Atlantic, reaching from Florida to Brazil.

In Florida the coral-reefs are built on, and close to the edge of the land, whence they are styled *Fringing Reefs.*

Off the north-east coast of Australia a great *Barrier Reef* of coral, about 50 miles in width, runs for a distance of 1200 miles parallel to the coast, but distant from it about 80 miles.

Many reefs of this "barrier" class occur in the other localities we have named, the reef running either some distance from a coast, or all round a central island.

The third class of coral island consists of a simple ring or circle of coral, inclosing a central salt lake or lagoon of no great depth. Such ring-like coral islands are called *Atolls* (see fig. 80).

Formation of Coral-reefs.—The water outside a barrier reef or an atoll always deepens very suddenly; often at a distance of only 100 yards or so from the reef the depth exceeds 2000 feet. Thus these coral formations must stand like walls or pillars on the ocean-floor. But we have said that the reef-building coral polyp cannot live at a depth exceeding 120 feet; therefore these nearly vertical masses of coral could not have been built up from the bottom of a deep sea.

Darwin's Theory of the Formation of Coral-reefs.—The generally accepted theory of the formation of coral islands is that which was first advanced about 1845 by Charles Darwin, after his return from a five years' exploring expedition in the Pacific, &c., on board the ship *Beagle.* He stated that barrier reefs and atolls are formed on land which has been *steadily sinking* for long ages.

In early days—perhaps at the close of the Tertiary Period—the Central Pacific was probably occupied by a considerable mass of land, possibly even by a continent. As this old land slowly sank beneath the waves, perhaps at the rate of a few inches every year, its mountain tops would at last form chains

of islands, around the margins of which the coral polyp built *fringing reefs.* Then as the land continued to sink *down*, the polyp continued to build *up.* As one layer or bed of the stony-cased polyps died, another flourished upon and above it.

But the coral polyp lives well only where the waves beat on it furiously so as to bring it much nutriment; and thus, although at the *outer or seaward edge* of each reef the growth is vigorous, there is but little growth at the inner margin next

Fig. 80.—An Atoll, or Ring-shaped Coral Island with Lagoon inside.

to the land. The result was that the fringing reef in time became a *barrier reef*, and an irregular ring of coral surrounded the very summit of each old mountain peak which still stood above the waters.

Finally, depression continuing, even this central peak at last disappeared, and only the coral ring was left as an *atoll* (fig. 80).

Thus coral-reefs mark, for the most part, areas of subsidence.

Slow Movements of the Earth's Crust.—We know that the globe we live upon is slowly cooling; and that, moreover, the interior of this globe is now cooling more rapidly than the exterior or crust. But when bodies cool they *contract*; and the more they cool the more they contract. One conse-

quence of the more rapid rate of cooling of the earth's interior as compared with that of its crust is, that the latter is thrown into folds or wrinkles in its attempts to follow the more quickly contracting interior. It is in much the same way that the wrinkled skin of a dried apple, or of an old person's hand, is produced, though in these cases the contraction is due to other causes than loss of heat. In the troughs or hollows of the great folds so formed on the surface of the earth lie the oceans, while the crests or highest parts of these main folds form our continents. But, as the cooling still goes on, parts of the crust slowly sink down here, or are pushed up there, as the crust tries to follow the continually contracting nucleus; and so changes in the relative position of land and sea are brought about; *here* the sea-bottom is elevated to form dry land, *there* the land is depressed beneath the level of the ocean. It may be taken as proved that it is not the *water* which rises and falls; it could not do so in one place without the same happening all over the world; it is the land which slowly moves, now down, now up. Probably every square foot of our continents has been—not once but several times—far below sea-level. Our stratified rocks were certainly formed under water; and the occurrence of marine shells as fossils, at heights in the Alps and in the Pyrenees (Eocene strata) of 10,000 feet, and in the Himalayas (Oolitic rocks) up to 18,000 feet, proves the immense elevation which in these regions has taken place. Even in our own islands fossil shells are found, for example, in the rocks on the top of Snowdon (3571 feet).

To quote Tennyson again,—

> "There rolls the deep where grew the tree.
> O earth, what changes hast thou seen!
> There where the long street roars, hath been
> The stillness of the central sea."

Among regions where slow *elevation* is now taking place we may name the *northern* part of Scandinavia. But round about Stockholm the land is stationary, while *south* of it the land has been gradually sinking at the rate of 2 or 3 feet per century;

so that at Malmö, in the south of Sweden, the sea now overflows one of the streets of the old town. The northern coasts of Asia and of America both show evidences of elevation within the Recent Period to the extent of 200 or 300 feet; but the south-west coast of Greenland has been slowly sinking for at least four centuries, so that many old buildings are there now under water; and the iron rings in the rocks to which the fishermen used to fasten their boats can be seen to be now many feet below the sea. The raised beaches, seen at many points round the coasts of the British Isles, tell a tale of elevation; while our submerged forests—exposed only at the lowest tides—prove a period of slight depression.

Fig. 81.—*Pholas*, a shell which, like *Lithodomus*, bores holes in limestone rocks in which to live.

The Temple of Jupiter Serapis. — The sea now stands in the courts of this famous temple, which is situated at Puzzuoli, near Naples. Of its forty tall marble pillars, only three remain standing. Up to the height of 12 feet above the ground these three pillars are as smooth as when built, but from the height of 12 feet to that of 21 feet they have been perforated by the marine boring shells called *Lithodomus*. Evidently the ground in this part of Italy must have been depressed to at least 21 feet below the sea-level; but the bottom 12 feet of the pillars was protected by matter—very likely volcanic ashes ejected from a neighbouring volcano—heaped round them so that the boring shells could only pierce the marble over a band of 9 feet. Since then, elevation must have taken place, for the temple now stands nearly at its original height: (see fig. 81).

TEMPLE OF JUPITER SERAPIS.

Table showing the recorded sequence of elevations, depressions, and neighbouring volcanic eruptions:—

B.C.	380	Eruption of Ischia.
„	105	First temple known to be in existence.
A.D.	79	Eruption of Vesuvius, Pompeii buried under ashes.
„	180	Second temple built.
„	230	Time of Alexander Severus. Sea encroaching.
„	300	Three eruptions of Vesuvius.
„	400	
„	500	
„	600 to 1100	Dark incrustations formed with serpulæ on columns. A sinking of 4½ ft. below the sea.
„	1198	A Solfatara eruption at Puzzuoli. First filling up with ashes to height of 7 ft.
„	1200	A fresh-water lake formed. A second incrustation to height of 8 ft. 8 ins.
„	1300	
„	1400	
„	1488	Earthquake of Puzzuoli. Second filling up with ashes.
„	1503	Land drying up.
„	1511	Land dry.
„	1538	Formation of the neighbouring volcano Monte Nuovo. Third filling up with ashes.
„	1600	Vesuvius in eruption.
„	1700	
„	1750	Temple dug out.
„	1800	Temple sinking.
„	1819	Temple sunk to sea-level.
„	1845	Temple sunk 2 ft. 4 ins. below sea-level.
„	1852	Temple recorded as rising.

CHAPTER XVIII.

VOLCANOES AND EARTHQUAKES: THE PRODUCTION OF MOUNTAIN-CHAINS AND OF METAMORPHIC ROCKS.

What is a Volcano?—Whatever a volcano may be, there is one thing which it certainly is *not*, and that is "a burning mountain". It may, from a distance, present the *appearance* of one; but when we closely examine the volcano we find something very different.

A volcano is a conical hill or mountain composed of material (volcanic ashes and lava) brought up from the interior of the earth through a pipe or vent. At the top there is a cup-shaped hollow called the crater.

A volcanic eruption generally commences by the discharge of immense quantities of gases (steam, carbonic acid gas, &c.) from the central pipe, by which the solid rocky floor of the crater is blown out. This is usually followed by the ejection of liquid rock from the pipe to the height of hundreds or even thousands of feet in the air. As this molten matter falls it cools and solidifies, forming volcanic ashes (see fig. 55). Lastly, a flood of molten rock or *lava* is forced up the pipe and fills the crater until at last it runs over at the lowest part of the crater wall, whence it descends the side of the volcano, destroying every living thing in its path, and looking by night like a river of fire. Thus at every eruption the volcanic cone increases in height and in breadth. The result often is that after a time the volcanic forces find it easier to break a new fissure or pipe to one side of the volcano, and there to issue, forming a minor or parasitic cone. Often the lava is injected into rents or cracks made by the upheaving forces in the sides of the volcano, and there it solidifies, forming sheets of igneous rock, which are known as dykes or trap-dykes.

Fig. 82.—Crater of a South American Volcano in active eruption. Several small scoria cones are seen within the crater.

Classification of Volcanoes.—Volcanoes which erupt more or less regularly and frequently, such as Stromboli in the Lipari Isles (which has an eruption every quarter of an hour), or Vesuvius, are called *active* volcanoes. Such volcanoes number over 300, and they are invariably found near the sea. They fringe the Pacific—all the Andes, the mountains of Central America, the Sea-Alps of North America, the Aleutian Isles, Kuriles, Japan, and the Philippines, being studded with

cones—and they extend from the Philippine Isles through the East Indian Archipelago into the Bay of Bengal. Bordering the Atlantic we have the magnificent cones of Hecla and Skaptar Jokul in Iceland, and others, almost their equal, in the West Indies. And lastly, in the Mediterranean there are the historic Italian cones (Etna, Vesuvius, &c.), and Santorin in the Grecian Archipelago: (see fig. 82).

Another class of volcanoes is styled *dormant* (or sleeping), because, although the cones belonging to this class are known to have erupted in historic times, it is now perhaps centuries since any lava streams flowed from their craters. Of such "dormant volcanoes" we may name the islands of St. Helena and Ascension (in the Atlantic), the noble cone of Teneriffe in the Azores, Aden (at the mouth of the Red Sea), &c. For many centuries before A.D. 79 Vesuvius was a dormant volcano, and its crater and cone were then covered with villages and vineyards. But in that year it burst forth into full activity, ejecting the enormous clouds of ashes and lava beneath which the old Roman towns of Pompeii and Herculaneum lie buried. An 'active' volcano may remain at rest for some considerable time, and the ejected volcanic scoriæ and lapilli previously ejected may, and frequently do, in the interval of quiescence decay into very rich soils. Forests then spring up, and the flanks of the volcano become covered with vegetation. When the lava flows out afresh, this vegetation is of course destroyed, and the soil beneath is burned to a brick-red colour. These burnt soils are often spoken of as *laterite*, and examples of them may be seen in the West of Scotland.

Lastly, there are known many eminences which present all the structure and appearance of volcanic cones, but which have shown no signs of activity in historic times; these are called *extinct* (or dead) volcanoes. Of such the best-known are those of Auvergne in Central France, and of the Eifel in Germany.

The remains of still older volcanoes occur in the west of Scotland, in the islands of Mull and Skye, but these are only the stumps or roots of the old cones which once reared their heads there; their craters, &c., have been washed away by

rain, rivers, ice, and the other agents of denudation during the long ages which have passed away since Tertiary times—the geological epoch when these Scottish volcanoes were formed.

Minor Signs of Volcanic Activity.—The mud-volcanoes or *salses* of the Crimea (conical hills of slowly flowing mud two or three hundred feet in height); the *fumaroles* (fissures from which steam issues); the *solfataras* (holes from which sulphurous fumes proceed) of Italy, &c.; and the geysers and hot springs of Iceland, the Yellowstone Park, &c., are signs of weak or decreasing volcanic activity in the special districts in which they occur.

Explosive and Effusive Action of Volcanoes.—Volcanic eruptions are in all cases accompanied by the expansion and escape of enormous quantities of certain gases, the chief of which is water-vapour. Upon the quantity of these gases, and the degree to which they are compressed by the surrounding rocks before they issue from the volcanic vent or crater, the nature of the volcanic activity mainly depends. It is thus possible to classify volcanoes according to the character and violence of the action which is going on within them:—

(*a.*) *Explosive Action.*—Where the escape of the highly compressed gases is accompanied by loud explosive sounds, and by the hurling of the molten lava to great heights into the air, together with the production of immense quantities of volcanic ashes, dust, and scoriaceous lava, we have what is termed "explosive" volcanic action. The lava streams which flow from the crater during such action emit huge volumes of steam, and are very cindery and pumiceous. Stromboli, Vesuvius, and Etna are examples of volcanoes in which the volcanic action is of the explosive or most highly active type.

(*b.*) *Effusive Action.*—Volcanic action is sometimes, however, unaccompanied by any of these obviously violent effects. In such cases there are no explosions; this being due to the small volume of the included gases, to the fact that they are not highly compressed, and also to the extreme fluidity of the molten rock or lava, which thus readily makes way for the escaping steam.

As a result of this, there is no sudden outburst, the lava is

not thrown into the air as is the case in explosive action; and the quantity of volcanic ash and scoria is very small, or there may even be none at all. The whole eruption consists of the quiet outflow of lava from the crater, or it may be simply from a fissure or fissures in the earth's crust. The great crater of Kilauea in the Sandwich Isles is of the effusive type; it emits enormous masses of lava which is extremely fluid, and which does not give off very much steam.

The old basalt-sheets of Abyssinia, and of Idaho in North America, which cover areas of hundreds of square miles, and which are not associated with volcanic tuffs or agglomerates, are examples of lavas which were exuded from fissures in the earth's crust by effusive action.

But effusive action may ultimately become converted into explosive action, and *vice versa*. Thus the crater of Kilauea in the Sandwich Isles was originally of the explosive type, but as its activity diminished, a gradual change to the effusive type took place. Even within historic times, however, this mighty volcano has more than once given signs of explosive action, with the production of volcanic dust, lapilli, and scoriæ.

Earthquakes.—Earthquakes are tremblings or shakings of the crust of the earth felt over wide regions, and produced by causes acting below the surface at depths usually, it is believed, of from two to five miles. Whatever the cause of earthquakes may be, it appears to be sometimes of an explosive nature, and it produces *waves* which travel through the rocks at the rate of several hundred feet per second. The point beneath the surface from which the impulse proceeds is called the *focus* or centre of impulse, and the vertical straight line joining this point with the surface is called the seismic vertical; while lines drawn on a map through all places where the shock is felt at the same time are called iso-seismic circles. Instruments used to detect slight earthquakes and to register their direction are called seismometers. Recent discoveries have shown that the slipping of the rocks along lines of fault, or the snapping of the rocks at the moment when a fault is first produced, are perhaps the principal and most frequent causes of earthquake shocks.

Earthquakes are sometimes felt over very large areas. Thus the earthquake of Lisbon (1755), which continued for five minutes, was felt in the Sahara, in Iceland, in Switzerland, and in the British Isles; at Lisbon 50,000 persons perished, being mostly drowned by the great sea-wave which resulted from the sudden disturbance of the sea-bottom near that port.

Earthquakes frequently produce a sudden and permanent elevation of the land. By the earthquake of 1882 the shore-

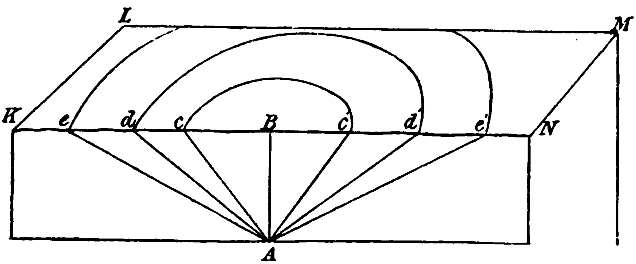


Fig. 83.—Centre of Impulse, and Iso-seismic Lines in Earthquake; K, L, M, N, surface of country; A, centre of impulse; A, B, seismic vertical; *c c'*, *d d'*, *e e'*, iso-seismic lines or circles.

line of Chili was elevated three feet; by that in New Zealand in 1805 a large tract of country was raised nine feet; &c.

Speaking generally, it may be said that earthquakes and volcanoes occur in *regions which are in course of elevation*; just as coral islands mark regions of depression.

General Structure of Mountain Chains.—We have shown that the ordinary "hills and valleys" which abound in every country are simply the result of denudation. The valleys are troughs or trenches which have been dug out chiefly by water; the hills are the harder remnants which have been better able to resist the forces of denudation. But true mountain chains have been formed in a different way, or at least denudation has in their production played only a subordinate part.

Mountain chains consist of ridges of very high ground (exceeding 2000 feet in altitude) which rise sharply from the

surrounding country, and which are narrow as compared with their great length.

When we examine the strata of which such chains are composed we find them almost invariably much *folded*, *contorted*, and *crumpled* and *faulted*. Very commonly in the centre of the chain there is a core of granite, and on each side of this we get such metamorphic rocks as gneiss, mica-schist, &c.; while on the flanks of the chain we find ordinary stratified rocks (see fig. 28).

The history of the formation of a mountain chain is probably somewhat as follows. In some area where subsidence is going on a great thickness of stratified rock is deposited, probably in shallow seas not far from land.

After many ages the contraction of the earth-crust (due to its slow or *secular cooling*) makes itself felt in this region, and a tremendous but steady side-thrust or horizontal pressure is exerted. By this pressure the rocks are jammed together sideways and are also pushed upwards; not suddenly, however, but at the rate it may be of a few yards or even feet per annum.

Lastly, when the rocks become elevated above the sea the forces which produce denudation begin to act upon them, carving out the softer and more broken parts of the chain into valleys, while the harder, compressed portions stand up as peaks or bosses.

The *age* of a mountain chain is inferred from the rocks which have been disturbed by it during its elevation. Thus in the Alps the Eocene strata are found much bent and folded. Therefore the Alps must have been elevated *since* the Eocene Period. The Scandinavian Range, on the other hand, is of great antiquity, for it is composed of folded and metamorphosed Archæan and Cambrian strata, while the Silurian rocks of the same district are almost unchanged.

The indurated shales, slates, and grits of Ordovician age which are so well exposed in the neighbourhood of Aberdovey have been subjected to severe—though slow and long-continued—earth movements, and are therefore much folded and faulted. Fig. 84 represents an anticlinal fold in the Ordovician coarse

Fig. 84.—Anticlinal fold in hard shale at Aberdovey, N. Wales.

slates at Aberdovey. The strata have there evidently been subjected to an enormous lateral and to a somewhat less vertical pressure, the greatest force having been exerted from the east, so that the fold is pushed in a westerly direction. The production of such a fold would probably be the work of hundreds—perhaps of thousands—of years. On the flanks of the fold it will be observed that each stratum of rock has been squeezed and drawn out, and that at the actual bend each stratum is slightly thicker than at the flanks. In other and similar cases the fold has not unfrequently snapped, the rocks on one side being afterwards thrust over and above the strata on the other side; in this way reversed faults and thrust-planes arise.

Pressure as an Agent in producing Metamorphism.—The *metamorphism* of rocks, by which limestone has been converted into marble; sandstone into quartzite; and shale first into slate, and ultimately into gneiss or mica-schist, we have treated of more fully elsewhere (see p. 139, and pp. 168, 170). But in the forces by which mountain chains have been formed, we see powers able also to bring about the metamorphosis of rocks. Pressure, when resisted or arrested, is converted into heat; and heat is a very powerful agent in producing a change in rocks. Now to elevate any mountain range pressure to an extent of which we can hardly form any comprehension, but which must have amounted to many tons per square inch, has been employed; and this pressure has always been resisted, and has finally been arrested by the weight and counter-pressure of the enormous mass of strata to be moved. We are not surprised, therefore, to find an abundance of metamorphic rocks in every lofty and ancient mountain-chain.

Metamorphic Rocks.

Agents of Metamorphism.—All the rocks which compose the crust of the earth have been more or less altered since the time of their original deposition or solidification. The changes which have been produced in the rocks are mainly due to the action, singly or combined, of the three following agents.

1. *Heat*—Contact or Pyro-metamorphism—produced by the intrusion of the melted matter which (now cooled down and solid) we know as granite, basalt, and igneous rock generally. By heat limestone has been changed into marble, sandstone into quartzite, &c.

2. *Water*—producing chemical or aqueous metamorphism. The rain-water which trickles *downwards* through the rocks always contains carbonic acid, whereby it is able to dissolve (especially) the carbonate of lime in rocks. The heated water which rises *upwards* from below can also dissolve many minerals, and even such metals as gold, lead, &c. The materials which the water dissolves and removes from the rocks in one place are frequently deposited by it in, around, and upon the rocks in another place. All rocks are more or less porous, and the water slowly soaks through them. The many cracks and fissures in the rocks also facilitate the passage of water. In course of time these cracks become filled up with mineral matter deposited on their sides by the waters traversing them, and thus *mineral veins* and *lodes* are formed.

3. *Pressure*—usually *lateral* or side pressure. The pressure exerted upon many rocks during the slow but long-continued movements of the crust of the earth has been enormous. By this pressure the particles of rocks have been caused to re-arrange themselves, so that shale has become slate, &c. Alterations in the rocks resulting from this cause—earth-movements producing great pressures—are known as *dynamo-metamorphism.*

Thrust-planes.—Among the very old rocks—such as those which form the Highlands of Scotland—the disturbing forces have often acted so powerfully (though slowly and during long periods of time) as to *thrust* the layers of the rocks over and along one another, producing what are called 'thrust-planes' —a term introduced into the science of geology only a few years ago, and resulting from the investigation of the officers of the Scottish Geological Survey. This sliding action has often resulted in the mingling together of portions of different rocks, and in so doing has produced an apparent metamorphism of the strata. It has also had the effect of carrying portions

of the rocks far from their normal position and line of outcrop.

It has been stated (see p. 79) that in a reversed or upthrow fault the hade or inclination of the fault is in the direction of the upthrow (see fig. 50). As a result of this 'overthrow' of the strata, older rocks are thrust over and above newer ones; so that the respective ages of the successive layers of rock as there revealed by their order of superposition (as seen in a well,

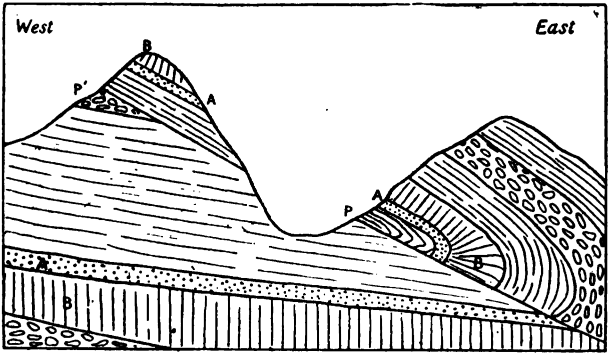


Fig. 85.—Thrust-plane—P, P'.
The letters A A and B B indicate strata which were once horizontal and continuous.

or bore-hole, for example) would be quite erroneous. It is only by tracing the beds along the line of fault; and by studying their fossil contents, that the true positions of the disturbed rocks can in such a case be made out.

Usually the amount of overthrow of the strata affected by a fault may be measured in feet or yards. There are cases, however, as in the Alps, the Appalachians, and the Highlands of Scotland, where the overthrow or "overthrust" of the older rocks over the newer ones may be measured in miles; and the greatest care has to be taken in such regions in determining the true order of superposition of the strata (see fig. 85).

Naturally, it is in districts where long-continued earth movements have taken place that this extreme form of reversed fault is met with. It does not follow that the most ancient

rocks of the globe are the only ones which have suffered; the Alps, which are largely composed of Triassic, Jurassic, and Tertiary strata, have perhaps suffered the most severely of any mountain range from the action of the internal forces which have caused the reversed faults and overthrusts.

The plane along which the more ancient strata have been thrust over the newer beds is usually more or less horizontal, rarely having a high angle as in the majority of normal faults. This plane is termed a "thrust plane", and may be defined as a reversed fault in a nearly horizontal position, and producing a horizontal displacement of the strata to the extent of thousands of feet or even several miles. The rocks which have participated in these tremendous earth movements, have been ground together, and in some cases broken up into breccias, while in other cases they have been partly fused, and then recrystallized, forming rocks now known as granulites and mylonites. In all cases these areas of disturbance show all the characters of extreme regional metamorphism, soft limestones being converted into hard crystalline marbles, crumbling sandstones into quartzites, and soft shales and mudstones into slates, schists, and gneisses. By 'regional' metamorphism is meant metamorphism on a large scale and as exhibited over extensive areas, such as we find in 'regions' where the rocks have been subjected to great *pressure* (due to earth-movements) at a time when they lay deep in the earth-crust.

METAMORPHIC IGNEOUS ROCKS.

Serpentine.—*Serpentine* occurs both as a mineral, forming part of other rocks; and massive, as a bed of rock itself. Chemically it is a *hydrated silicate of magnesia*, *i.e.* silicate of magnesia combined with water. It is a dull soft rock of a green or greenish-yellow colour, often mottled. It received its name from its supposed resemblance to a serpent's skin.

Serpentine appears to have been formed by the alteration of some ultra-basic rock containing much olivine, as crystals and outlines of the crystals of this mineral are often found in serpentine.

Serpentine is not a common rock. In England it forms the beautiful cliffs of the little "coves" near the Lizard in Cornwall; it also occurs in Anglesea; and at several places in Scotland, as on the Ayrshire coast, in the Hebrides, and along the Grampians. When polished it is used for decorative purposes.

There are other rocks of an obscure nature—certain magnesian schists, for example, which are probably volcanic tuffs altered by the deposition of matter from the heated waters which have traversed them since their formation.

Metamorphic Aqueous Rocks.

1. **Marble.**—Marble is a crystalline granular rock composed of carbonate of lime. It has been produced from various kinds of limestone by the action of intense *heat*, due usually to the proximity of some igneous rock in a melted state. The presence of *water* seems also necessary to the change, and at the time of its metamorphosis the rock would also be under great *pressure*. In fact these three agents—heat, moisture, and pressure—have been the principal agents in producing all the metamorphic rocks. Marble is usually white in colour, but is sometimes found yellow, gray, or red.

As long ago as 1790 Sir James Hall succeeded in converting chalk into marble by heating it in closed gun-barrels. Many sections or exposures of the strata are known where limestone is seen to be converted into marble where it is in contact with dykes of basalt or some other igneous rock, while at a little distance from the intrusive rock the limestone resumes its ordinary character. Examples of this may be seen on Rathlin Island, off the north coast of Ireland; and in Camps Quarry, near Edinburgh. Marble may be of any geological age; the famous statuary marble of Carrara, in Italy, is an altered Jurassic limestone.

2. **Quartzite.**—Quartz rock or quartzite is a very hard compact rock, usually whitish, but often gray, pink, or red in colour. When broken it has a lustrous or shining fracture, very

different from the dull surface of sandstone. Microscopical examination shows quartzite to be composed of more or less rounded grains of quartz-sand cemented together by silica, which fills up all the interstices between the grains. This siliceous cement was doubtless deposited by heated water when traversing the rock. Quartzite is clearly an altered sandstone. In the north-west of Scotland Lower Cambrian quartzites form the mountains of Sutherlandshire. In England the Cambrian quartzites of the Lickey Hills (N.E. Worcestershire), and of the Hartshill Range, near Nuneaton, are well known.

3. **Foliated Rocks: Gneiss and Mica-schist.**—In the ordinary laminated and stratified rocks each lamina or layer can be traced for a considerable distance, the upper surface of each lamina being constantly parallel to the lower. The foliated rocks, on the other hand, consist of *minerals*, also arranged in layers, or rather in *leaves*. But each leaf can only be traced for a short distance—usually for not more than an inch or two.

This foliated structure must have been produced since the original formation of the rock; therefore all foliated rocks are *altered* rocks. Such a structure is also called *schistose*, because the rock splits more or less readily in the direction along which the "leaves" of mineral matter run (see fig. 42).

Gneiss.—Gneiss is a metamorphic rock consisting of orthoclase felspar, mica, and quartz. It will be observed that these are the same three minerals which constitute granite. But gneiss differs from that truly igneous rock in the minerals being roughly arranged in layers or "leaves", and not thoroughly intermixed as they are in granite.

Mica-schist is a metamorphic rock composed of the two minerals, quartz and mica, arranged in wavy, irregular leaves, layers, or laminæ.

Mica-schist and gneiss have probably often been formed out of ordinary aqueous rocks by the usual agents of metamorphism —heat, the chemical action of water, and pressure; but of these three it is *pressure* which in the case of these two rocks has probably done most of the work. Recent investigations have shown that gneiss and schist have in many cases also been

formed out of *igneous* rocks by the same agencies of metamorphism which produce such marked changes in aqueous rocks.

Such rocks as gneiss and mica-schist are of great geological age. Gneiss is a characteristic rock of the oldest geological formation, that which is now usually called *Archæan* or *Pre-Cambrian*, though it was formerly known as *Laurentian.*

In the British Isles these old foliated rocks occur in Western Scotland and in the Outer Hebrides. Anglesea is largely composed of schistose rocks; and they crop out again at the Lizard and at one or two other points in South Devon. Gneiss occurs at one spot in Central England — Brazil Wood, in Charnwood Forest. Here it is clearly the result of an intrusion of granite into a slaty rock.

Metamorphism around Plutonic Masses.—It has been known for a long time that a marked mineralogical change occurs in those stratified rocks through which any molten rock, such as granite in a state of fusion, has protruded itself. This change is most evident in the immediate neighbourhood of the granitic boss or dyke, and becomes less perceptible as we recede from the igneous mass. The stratified rocks surrounding the igneous boss have been metamorphosed, the change in mineral composition being accompanied by a change in texture. Where the changes have taken place only in the immediate neighbourhood of the igneous mass we term it contact metamorphism. Thus at Charnwood Forest we have granitic veins penetrating beds of coarse slate, with the result that in the neighbourhood of the veins the slates have been converted into a kind of gneiss or schist; a change which is accompanied with the formation of garnet and other minerals in the gneissose rock.

In other cases sandstones have been partly fused and cemented together; clays have been baked and now form porcellanite; while limestones have been converted into marble in which we sometimes find serpentine, idocrase, and garnet.

In the case of certain granite bosses which are more or less circular in outline, the region of contact metamorphism is also circular; the effects of the metamorphic agent gradually be-

coming less and less perceptible as we pass outward from the boss of granite. Such a zone of metamorphosed rocks surrounding a central igneous mass is known as an *aureole.*

In Forfarshire three successive zones of contact metamorphism can be distinctly made out around the huge plutonic masses of that district. Where they are in contact with the granite the schists are characterized by the mineral *sillimanite* imbedded in quartz; a little farther from the granite the mineral *kyanite* becomes prominent; and at a still greater distance the mineral *staurolite* predominates in the schists.

In the south-east of Ireland the Ordovician strata have been invaded by enormous masses of granite, which have for a distance of over a mile from the intrusive rock converted the Ordovician shales into schists.

Distinctive Characters of Gneisses, Granulites, and Schists.

The metamorphic rocks termed **Gneisses,** whether resulting from the metamorphism of igneous or of aqueous rocks, are characterized by the *foliated arrangement* of their minerals. In many cases this foliation is the only feature which distinguishes them from granite. Usually, however, the metamorphic agencies have by their action introduced many accessory minerals into the gneissic rocks, such as hornblende, garnet, and tourmaline.

The folia, or leaves of mineral matter forming gneiss, vary very considerably in thickness and arrangement; these folia being as a rule much coarser than those in schists. The schistose structure in gneiss, due to the abundance of the folia of mica, is also much less perfect than in the schists.

Gneisses have usually resulted from metamorphic agencies acting over wide areas, and are examples of rocks produced by regional metamorphism. In some cases it is possible to trace the passage of gneiss into granite, and also to see the actual transition of gneiss into mica-schist.

The typical gneiss consists of folia or leaf-like aggregations

of orthoclase, of quartz, and of mica. Most gneisses are very old rocks, and the most typical examples are found in the Archæan or Pre-Cambrian strata. It is now recognized that in many cases gneiss has resulted from the crushing and shearing of some plutonic rock, such as granite.

Granulites are metamorphic rocks consisting essentially of a *granular* aggregate of felspar and quartz, along with small

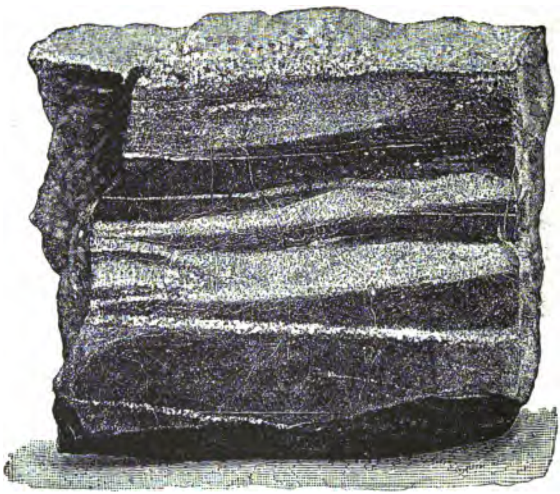


Fig. 86.—Hand-specimen of 'Granulite', Kildown Cove.—After Major-General C. A. M'Mahon. (Reproduced from the Quarterly Journal of the Geological Society.)

red garnets. Other minerals having a metamorphic origin are invariably present, such as kyanite and tourmaline. Granulite is a rock which has resulted from regional metamorphism, the fine-grained granular structure from which the rock derives its name having resulted from the crushing down of igneous and metamorphic rocks. Granulites occur with gneisses along the great tault-slips of the Scottish Highlands, the rocks having been ground to a powder along the lines of fault by the lateral movement or shearing of the rock-masses. The heat produced by this shearing of the rock-masses was sufficient in many cases to remelt the ground-up rocks, and the molten material, solidify-

ing and crystallizing out under pressure, produced a more or less granular rock, now termed "granulite". The granulites are of most varied composition, and although the common granulite contains principally the minerals felspar and quartz, yet the quartz may be replaced by augite—when we have a rock similar in composition to gabbro—or by hornblende—when we have a rock resembling granular diorite (see fig. 86).

Schists.—These are metamorphic rocks in which the foliation is usually very perfect, and but little interfered with by the presence of minerals in large crystals. The difference between the mineral constituents of the successive layers in a schist is not so marked as in the coarser rock called gneiss, so that some of the folia may be hidden, especially if the folia are much crumpled. The rock easily cleaves in a direction parallel to its folia. In mica-schist the folia of mica appear to constitute the whole mass of the rock, and conceal the quartz and other minerals. When large crystals of garnet occur in the schist, the folia flow around the crystals and resemble an eye or kernel. This is known as 'eye' or 'augen' structure, and is frequently seen in both gneisses and schists (see fig. 87).

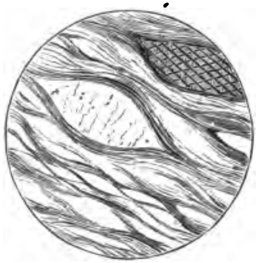


Fig. 87.—Hornblende-gneiss with 'eyes'; or "augen-structure".

Schists are usually named after the most abundant mineral which they contain. Thus hornblende-schists consist principally of hornblende, with inconspicuous folia of quartz, and even of felspar and mica. Chlorite-schists are composed almost wholly of the green mineral chlorite; they usually cleave very perfectly in a direction parallel to the lines of foliation, and in this respect resemble the mica-schists.

4. **Dolomite or Magnesian Limestone.**—Dolomite occurs both as a mineral, and (massive) as a rock. It is named after Dolomieu, the great French geologist.

When pure it is composed of nearly equal parts of carbonate of lime and carbonate of magnesia; hence the rock dolomite

is commonly called magnesian limestone. Such a rock has probably been formed by the percolation of water (containing carbonate of magnesia in solution) through a limestone. The water dissolved out some of the limestone and carried it away, and left carbonate of magnesia in its place.

Hence dolomite is a metamorphic rock, in producing which the principal agent has been the chemical action of water.

There is a well-known bed of dolomite in the Permian Formation which extends from South Shields to Nottingham. The same rock is magnificently developed in the "Dolomite Mountains" of the Eastern Alps.

5. **Slate.**—Slate is an old clayey or shaly rock which has undergone great pressure — usually at a high angle to its original bedding-planes—whereby the particles of mud composing the rock have been rearranged, and a very compact and fissile structure (known as *slaty cleavage*) imparted to the rock. The cleavage-planes always lie at right angles to the direction of the force which produced them.

PART II.

SECTION I.—CLASSIFICATION OF ANIMAL AND VEGETABLE LIFE.

CHAPTER XIX.

PALÆONTOLOGY; OR THE STUDY OF THE REMAINS OF ANIMALS AND PLANTS FOUND AS FOSSILS IN THE STRATIFIED ROCKS.

Biology, or the Study of Life.—The study of living things, whether animals or plants, is known as Biology; and this is divided into Zoology—the study of living animals; and Botany—the study of living plants.

But embedded in the rocks we find the remains of animals and of plants—fossils—which lived during former stages of the earth's history; and the study of these is called Palæontology (Greek *palaios*, ancient; *onta*, beings; *logos*, a discourse).

Fig. 88.—Endogenous Plants.

1, Section of the stem of a Palm: *c*, Portion of stem, natural size, showing the ends of the bundles of woody fibre. 2, Endogenous Leaf, showing its parallel veins. 3, Monocotyledonous Seed, showing its single cotyledon: *a, a*, Cotyledon. 4, Germination of Palm: *c*, Cotyledon; *b*, Albumen; *d*, Plumule; *e*, Radicle issuing from a short sheath. 5, Flower of Endogen.

Those who wish to understand fossils—to become *palæontologists*—should commence by studying living beings—the shells, fish, plants, &c., which now inhabit the surface of the earth. These can be obtained in far greater perfection than the fossil forms. Fossils are usually fragmentary and imperfect, and as a rule only the hard parts of the organisms are preserved.

Many thousands of different kinds or species of both living and fossil beings are known; and doubtless many remain yet to be discovered.

In studying all the myriad forms which have or formerly had life, the first thing to do is evidently to *classify* them, putting those which are more or less alike in the same class.

Classification of Plants.—Botanists have arranged all plants under the two great heads of PHANEROGAMS (flowering) and CRYPTOGAMS (flowerless). The former have distinct seeds, flowers, and fruits; the latter have neither true flowers nor fruits. The rose, apple, and oak will serve as examples of phanerogams; and ferns, mosses, and seaweeds of cryptogams.

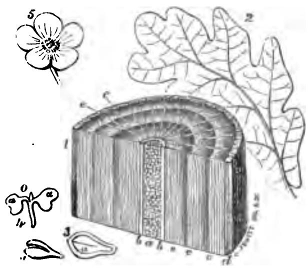


Fig. 89.—Exogenous Plants.

1, Section of a branch of three years' growth. *a*, Medulla or pith. *b*, Medullary sheath. *e e*, Medullary rays. *c c*, Circles of annual growth. *d*, Bark. 2, Netted veined Leaf of Exogen (Oak). 3, Dicotyledonous Seed of Exogen. *a a*, Cotyledons. 4, Germination of Dicotyledonous Seed. *a a*, Seed-leaves or Cotyledons. *o*, Plumule. 5, Exogenous Flower (Crowfoot).

The flowering plants or Phanerogams are again divided into *Dicotyledons*—plants having *two seed-leaves*, net-veined leaves, and wood growing in rings, as our forest trees, our roses, &c.; and *Monocotyledons* — plants having only *one seed-leaf*, and parallel-veined leaves, as grasses, palms, orchids, &c. The dicotyledons are also known as EXOGENS—*i.e.* growers from the outside, because their stems increase in thickness by the addition annually of a ring of wood to the *outside* of the stem or trunk, just between the wood and the bark. The monocotyledons are frequently called ENDOGENS—their growth taking place from *within*, *i.e.* from the central part of the stem (see figs. 88 and 89).

Still another way of arranging the flowering plants is to divide them into (1) *Angiosperms* (seeds inclosed in a seed-vessel or ovary), which include both the dicotyledons and the monocotyledons; and (2) *Gymnosperms* (seeds bare or naked), including the plants known as conifers, cycads, &c.

The flowerless plants or cryptogams (also called *acotyledons*, because, having no seeds, they can have *no* seed-leaves) include ferns, horsetails, mosses, fungi (mushrooms), club-mosses (lycopods), lichens, and sea-weeds.

Occurrence of Plants as Fossils.—No fossil plants are known from the Archæan Formation, although it is possible that the seams of *graphite* in the Laurentian rocks of Canada may have been derived from plants.

Neither have any *undoubted* plant-remains as yet been obtained from Cambrian strata; but in sandstones of this age, in North America and in Sweden, markings which resemble sea-weeds ("fucoids") have been found. To one of these the name of *Eophyton* ("dawn-plant") has been given.

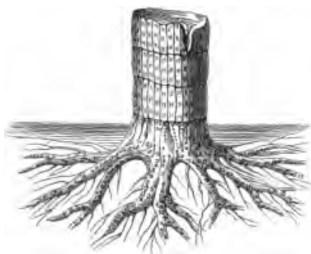


Fig. 90.—Sigillaria in a Coal-mine near Liverpool.

The British Ordovician strata have as yet yielded only a few plant-remains, these being the remains of certain sea-weeds (algæ).

It is in the Upper Silurian rocks that—in the British Isles, at all events—we find the first undoubted though scanty remains of land-plants. In the gritty sandstones of Denbighshire, which are of the same geological age as the Wenlock limestone, Dr. Hicks has recently found the stems of a lycopod (club-moss), which has been named *Berwynia Carruthersi*, together with certain curious small round seed or "spore-cases", much like others which occur in the Upper Ludlow Beds, which have been named *Pachytheca*, and which are also thought to belong to the lycopods, though they have also been assigned to the sea-weeds.

The Devonian rocks contain evidence of the existence of a land flora of considerable luxuriance. Horsetails (*Equisetum*), club-mosses, and ferns appear, together with the first *conifers* (cone-bearing trees allied to our firs and pines).

The Carboniferous flora—of whose matted remains our coal-

seams are composed—consisted mainly of gigantic cryptogams, with a few conifers. The horsetails (*Calamites*, &c.) and lycopods (*Sigillaria*, *Lepidodendron*, &c.) flourished exceedingly, and grew to the size of our forest trees (see figs. 90 and 91).

The Permian plants resemble, and are closely allied to, those of the Carboniferous epoch. They include the few first Cycads.

In the Triassic strata the fossil plants are mostly ferns, equisetums, and conifers. But the remarkable plants called *Cycads* are here first found in abundance. In outward form they resembled small palm-trees, but their true relations are with the pines and firs. In the British Isles, however, the Trias contains practically no fossils.

Fig. 91.
Lepidodendron Sternbergii.

The Jurassic beds contain plant-remains differing essentially from those of the Palæozoic rocks. This Jurassic flora is characterized by the abundance of gymnosperms (plants with naked seeds), including conifers, cycads, &c.; the conifers resembling our pines, yews, and cypresses.

The Cretaceous strata of the British Isles contain but few plant-remains, and those (mainly found in the fresh-water beds of the Wealden) are very similar to the Jurassic plants. But at Aix-la-Chapelle in Germany, and in the western territories of the United States, sandstones, &c., belonging to the *top* of the Cretaceous series occur, and these contain the first evidences of a well-developed angiospermous and dicotyledonous flora. Leaves and wood of the oak, fig, walnut, magnolia, laurel, &c., abound. Thus the Upper Cretaceous flora is the first which resembles that of the present day in containing an abundance of true forest trees and flowering plants.

As we advance upwards through Tertiary and Quaternary strata, the assemblage of fossil plants found in each set of beds becomes more and more like that of the present day. In the British Eocene strata alone, 200 species of angiosperms have been found—the first appearance in the British Isles of plants of a high degree of organization.

The flora of the Older Tertiary rocks is remarkable for its great extension towards the north, many species of fossil trees having been obtained from the Eocene strata of Spitzbergen and Greenland.

Classification of Animals.

General Scheme of Classification of Animals.—Zoologists have divided all animals into (1) *Vertebrates* (possess-

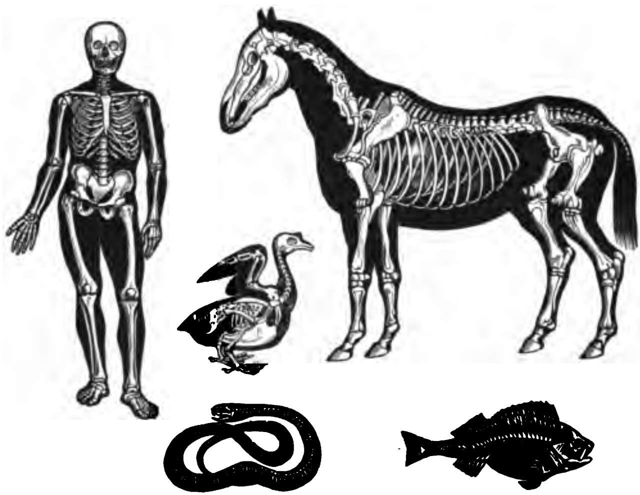


Fig. 92.—Examples of Vertebrates.—*Man, Horse, Bird, Snake,* and *Fish*: to contrast with the Invertebrates shown in Fig. 93.

ing a backbone), such as *man*, the *horse*, *fishes*, *birds*, &c.; and (2) *Invertebrates* (without a backbone), as *worms*, *crabs*, *insects*, &c.

The Vertebrata constitute a single sub-kingdom; but the Invertebrata are divided into eight sub-kingdoms.

Each sub-kingdom is divided into *Classes*; the classes are separated into *Orders*; the orders into *Families*; the families into *Genera*; and lastly, the genera into *Species*.

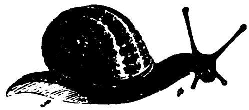
Meaning of the terms Species, Variety, Genus, Family, and Order.—For the purposes of classification and convenience, and in order to understand the relationships which

exist between the various members of organized beings, it is imperative that those forms of animal and of plant life which most nearly resemble one another should be grouped together.

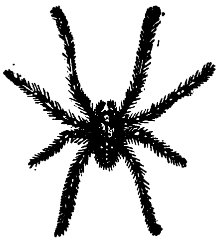
Species:—Thus all those individuals of either the Animal or Vegetable kingdoms, which possess in common a set of *constant*

Insect—Humble Bee.

Insect--V-Moth.



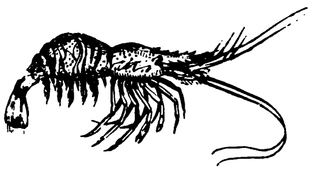
Garden Snail.



Garden Spider (an Arthropod).

Salt-water Mussel (a Lamellibranch).

Crab (a Crustacean).



Prawn (a Crustacean).

Fig. 93.—Examples of Invertebrates.

characters, and the whole of which form a distinct type of animal or vegetable life, would constitute a "species". For example, all the individual remains of the trilobite *Phacops caudatus* are alike; they all have the same number of abdominal and thoracic segments, the characters of the head-shield are precisely similar in all the specimens which have been found, &c. And more-

over this *Phacops caudatus* is a distinct and well-defined type of organism. It therefore constitutes a "species". Thus any given species consists of all those individuals (whether living or fossil) which are related to one another with no greater differences than may be seen—for example—between parents and children.

Variety:—Here and there, however, it sometimes happens that examples of certain species are found, which present constant though very slight differences from one another. These differences are the result, it may be, of some peculiarity in the food, the amount of light, or the character of the water, &c., in which the organism lived. It still retains the undoubted characters which are peculiar to its species, but some of these characters have been slightly modified. We have here an example of a *variety* of the species in question. For example, the species of lamellibranch termed *Saxicava rugosa*, from the marine glacial beds of the Clyde, is a well-known form of mollusc; a variety of it, however, is also known, which is termed *Saxicava rugosa* (var. *arctica*). It can be well understood, however, that there is great inconvenience attending the use of the term 'variety' as applied to fossil forms of life; this being due to the nature of the material the palæontologist (as the student of fossil forms is termed) has to deal with; its limited amount; and the crushing and consequent distortion to which the fossil forms have frequently been subjected.

A "variety" may be defined as a sub-species, the individuals of which do not differ sufficiently from the main or parent stock to be considered as a distinct or separate species, although they possess certain minor characteristics which entitle them to some consideration and to a third or distinguishing name.

Genus (plural, *Genera*):—Those species which (although retaining each their individual and distinctive specific characters) yet still possess certain *prominent* characters in common are put together into one set or "genus". Thus the three Brachiopods, *Pentamerus Knightii*, *Pentamerus oblongus*, and *Pentamerus galeatus*, represent three individual species, and can be readily distinguished from one another. But they are also most

closely related to one another; they are each built on the same lines; and their internal structures are but modifications of one type. These three species of brachiopods, then, belong to one and the same *Genus*, viz. the genus *Pentamerus*.

Family:—When a number of genera agree in certain important structural characters they are placed together to form a "Family".

Thus the four genera of Cephalopods known as *Trocholites*, *Gyroceras*, *Hercoceras*, and *Nautilus*, are all characterized by having a spiral inrolled shell, the coils of the shell all lying in one plane, its aperture being contracted and simple. These four generic types therefore form one family, the *Nautilidæ*.

Order:—Lastly, the families are grouped together into "Orders". For example, it can be clearly seen that the various families which contain the trilobites must be closely related to one another; but that they differ in many points from all the other crustacea. It is natural, therefore, that these families should be put together or grouped under the head of the order *Trilobita*. The trilobites are all more or less tri-lobed, and have a distinct head, thorax, and abdomen. The segments of the thorax are movable upon one another, but the abdominal segments are "fused" or grown together. They possessed jointed legs, and a gill apparatus. These characters are common to all the families of trilobites; but are not possessed as a whole by any of the other families of the class of animals termed Arthropods.

The Three Kingdoms of Nature.

All matter can be classed as either (1) Mineral, (2) Vegetable, or (3) Animal; and these three divisions are often spoken of as the Three Kingdoms of Nature.

The Mineral Kingdom consists of matter which is inanimate or without life, and which gives no direct evidence of ever having possessed life. Thus air, water, granite, slate, a crystal of quartz, &c., are examples of common kinds of matter which belong to the mineral kingdom. All mineral substances

are devoid of distinct working parts or "organs", and hence they are also called *inorganic* substances.

The Animal and the Vegetable Kingdoms consist of living matter—or of matter which has clearly once formed a part of some living thing, as evidenced by its retaining the shape, structure, &c., of that thing. All living matter is organized; and we can ordinarily recognize in any animal or plant the numerous and distinct parts (called its *organs*) by which its functions are carried on. Hence the Animal and the Vegetable Kingdoms may be grouped together under the name of *organic* matter.

The plants (which constitute the Vegetable Kingdom) differ from the animals chiefly in their power of subsisting upon inorganic matter alone. Thus plants derive their nourishment from the water and the air; there being a little mineral matter dissolved in the water. Animals, on the contrary, require plants, or other animals—or both—as food, in addition to mineral matter, for their healthy sustenance.

How Animals are named.—In science, every known animal—and indeed every plant also—has been allotted two names. The first of these is its *generic* name, and the second is its *specific* name. These (scientific) names are in Latin, so that they can be understood by the students of all countries. For all men of science have, or are supposed to have, some knowledge of Latin. Thus all elephants belong to the *genus* (plural, *genera*) *Elephas*; but even among living elephants there is sufficient difference between those which inhabit Central Africa and India respectively to justify the one being known as *Elephas Africanus*, and the other as *Elephas Indicus*. Then the extinct species of elephants whose bones we find in the newer rocks differ from all the living forms; thus the woolly elephant or mammoth is called *Elephas primigenius*, and so on.

The Latin or scientific name of an animal or plant ought properly to indicate its principal personal peculiarities; thus, *Avicula contorta* means the "twisted wing-shell"; but many species have been named after their discoverer, as the Cambrian trilobite *Paradoxides Hicksii*; or from the place where they abound, as the Liassic crustacean *Eryon Barrovensis*, &c.

CLASSIFICATION OF ANIMALS.—THE INVERTEBRATA.

The Invertebrata include all those animals which do *not* possess a backbone or vertebral column. They may be divided into eight groups or "Sub-Kingdoms".

Sub-kingdom I. — Protozoa. — The Protozoa are the most simply organized of all animals, being little more than specks of jelly-like matter, some of which—as the foraminifera—have the power of covering themselves with a shell made of carbonate of lime secreted from the waters of the ocean. Although so small, the forams are important by reason of their countless numbers; and from the doubtful *Eozoon* of the Laurentian rocks to the *Globigerina* of the Chalk, and the *Nummulite* of the Eocene Period, they have played an important part in the formation of the stratified rocks.

Sub-kingdom II.—Porifera, or Spongida.—The soft parts of many sponges are supported by rays or spicules composed of siliceous or calcareous matter; and it is these spicules only which we find fossil. The oldest known British fossil sponge is *Protospongia fenestrata*, which occurs in the Lower Cambrian strata at St. David's in South Wales (in the Menevian Beds).

Sub-kingdom III. — Cœlenterata. — The *Cœlenterata* (Greek *cœlus*, hollow; *enteron*, intestine) are divided into two *classes*—the *Hydrozoa* and the *Actinozoa*.

The Hydrozoa include the jelly-fishes and other forms which have no hard parts, and which we cannot, therefore, expect to find as fossils. But in this class we have also the important extinct *order* of the *Graptolites*. They consist of numerous cells arranged on one or both sides of an axis, which may be either straight or curved. Each cell contained a small organism, so that the entire structure was that of a compound zoophyte, something like the "sea-firs" of the present day.

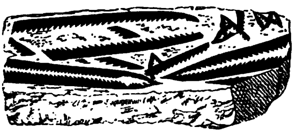


Fig. 94.—Piece of Shale containing Graptolites.

Graptolites are found only in the Upper Cambrian, Ordovician, and Silurian strata. The name is derived from *grapho*, I write; and *lithos*, a stone; because shaly rocks covered with these fossils look as if they had been scribbled upon (see fig. 94). The first graptolite belongs to the genus *Dictyograptus*, and occurs in the Lingula Flags. It is composed of a great number of radiating branches connected together by minute cross-rods, thus forming a network. *Didymograptus Murchisoni* is a well-known Llandeilo graptolite, consisting of two branches united together to form a **V**, and having the cells on one branch almost face to face with those on the other branch.

The value of the graptolites to the stratigraphical geologist is very great, for owing to the fact that particular horizons or zones are characterized by certain species of graptolites (which are never found in the rocks above or below their own particular zone), it is possible by means of these fossils to correlate and classify together beds of rock which geographically are widely separated.

The Actinozoa include all the corals, together with the sea-anemones, &c. Some corals are 'simple', growing individually and separately, and these usually have a cup-like form. But the reef-building corals are 'compound', clustering together and growing one upon another. In Britain the first known corals occur in the Cambrian strata of Wales and Scotland, though in these very old rocks they are but few in number and of scanty occurrence.

The Palæozoic corals are remarkable for having their stony divisions or *septa* in multiples of *four*; while the corals of the Neozoic rocks[1] have them in multiples of *six*.

Old coral reefs are found in several of the geological formations, as the *Wenlock Limestone*, the *Devonian Limestone*, the *Coral Rag*, &c.

Sub-kingdom IV.—Echinodermata.—The name "*Echinodermata*" is derived from the *spines* which cover the sea-

[1] By "Neozoic" we mean all the stratified rocks which have been formed since Palæozoic times. Thus the Neozoic rocks include both the Mesozoic and the Cainozoic series.

urchins, &c., which belong to this sub-kingdom. There are several important *orders* of Echinoderms, including—

1. *Crinoidea*—encrinites or sea-lilies—animals with a stalk, and having a cup-like head surrounded by tentacles; they grew rooted in the sea-mud. The oldest crinoid (*Dendrocrinus*) occurs in the Tremadoc rocks (Upper Cambrian) at St. David's. Crinoids were very common in Palæozoic, but less so in Mesozoic times; while now they are dying out, a few specimens only lingering at the bottom of deep seas (see fig. 95).

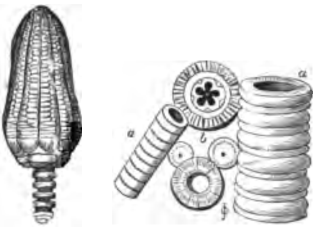


Fig. 95.—Encrinites or Sea-lilies.

aa, Portions of jointed stems; *b*, separate joints. The cup and head, with tentacles closed in, is seen on the left.

2. *Asteroidea*, or star-fishes. The first known star-fish (*Palæasterina Ramseyensis*) is found in the Upper Cambrian Formation.

3. *Echinoidea*, or sea-urchins. The first fossil sea-urchin (*Palæechinus*) is found in the Upper Llandovery rocks (Silurian).

Sub-kingdom V.—Vermes or Annulosa.—Here we find the worms or "ringed animals". Although so soft, yet the burrowing worms called annelids or the Annelida, which live on sandy sea-shores, have left traces of their presence in the shape of trails and burrows in the lowest Cambrian strata.

Sub-kingdom VI.—Arthropoda or Articulata.—The Arthropods have a soft body protected by a hard jointed skin like that of the lobster, spider, beetle, &c.

The most important *class* among the Arthropods is that of (1) the *Crustacea*, to which our living crabs and lobsters belong; and which is strongly represented in the Palæozoic rocks by the now extinct *trilobites*.

The Trilobite is so named from the *three lobes* into which its body was longitudinally divided. It inhabited the muddy bottoms of shallow seas, and was able to roll itself up like a hedgehog in case of need; many specimens have been found which had evidently died while in that position. Of living animals the common wood-louse, and the king-crab of the West

Indies, most resemble the trilobite. The first trilobites occur in the Lower Cambrian Formation, and belong to the genus *Olenellus*, which was succeeded first by *Paradoxides* (Middle Cambrian) and then by the allied genus *Olenus* (Upper Cambrian). The trilobites increased in numbers until the Upper Silurian epoch, and hundreds of very beautiful specimens of such genera as *Phacops* and *Calymene* have been obtained from the Wenlock limestone at Dudley and elsewhere. After this

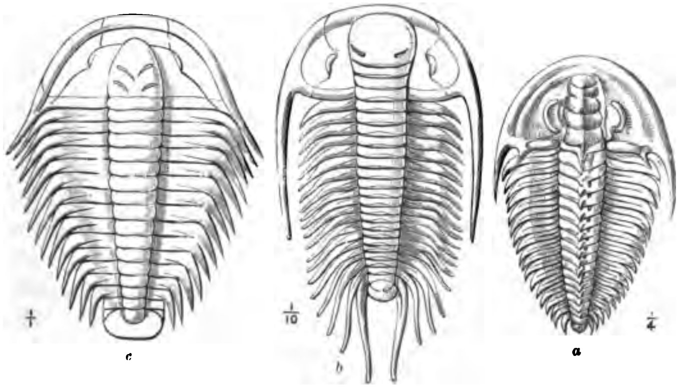


Fig. 96.—Three Cambrian Trilobites.
(*a*) Olenellus Callavei. (*b*) Paradoxides Davidis. (*c*) Olenus micrurus.

they decrease; and the last few trilobites (which belong to the genus *Phillipsia*) are found in the Permian strata. Some trilobites are only a fraction of an inch in length; but the largest British trilobite (*Paradoxides Davidis*) attained a length of nearly two feet (see fig. 96).

Mr. C. D. Walcott, an American geologist, has lately shown that the ventral or under side of the trilobite's body was covered with a hardened arch of the skin or integument, and that to each segment or ring of the animal's body was attached a pair of limbs; the head being provided with four pairs of jaws. A stratum of the Hudson River Shales, New York State, has recently yielded a number of specimens of a trilobite (*Triarthrus becki*) in a remarkably fine state of preser-

vation. These specimens not only show the appendages or limbs just mentioned, but also reveal the fact that the trilobites were provided with comb-like gills, and with long jointed feelers or antennæ which were two in number, and which projected from the head of the animal.

Fig. 96 *a* is a restoration of a trilobite (*Olenellus Callavei*) discovered by Prof. Lapworth near the base of the Comley or Hollybush Sandstone (Lower Cambrian), at the foot of Little Caradoc, in Shropshire. This crustacean, one of the very first or oldest of the trilobites, is about six inches in length by four inches in width. Under the microscope the whole of its surface is seen to be ornamented by a network of fine lines inclosing polygonal areas, so that even small fragments of this species of trilobite may be recognized by this peculiarity. The head-shield is semicircular in form and is prolonged into long or short posterior spines. The eyes are large. The thorax consists of a number of segments which vary in different species of Olenellus, ranging from 13 to 26 in number. The tail or pygidium is sometimes long and styliform; in some species, however, it is similar in form to that of Paradoxides. This fossil Olenellus—like many other species of extinct animals—has never yet been found perfect and complete in one single specimen. Fragments are found here, and fragments there; and in such cases it is the work of the palæontologist—as the student of fossils is termed—to piece them together, and so to restore for us the perfect animal.

(2) Insects form the class *Insecta* of the sub-kingdom Arthropoda, and the first insects at present known occur in the Lower Silurian rocks of the north of France. In our own islands the first fossil insects are found in the Coal-measures (Carboniferous Formation).

Sub-kingdom VII.—Molluscoida.—This division of the Invertebrata is so named ("*molluscoida*" means "like, or resembling a shell") because of the strong resemblance which some of its members present to the true molluscs, or shell-fish proper.

The class *Brachiopoda* includes all the so-called "lamp-shells", which are bivalves, having one valve smaller than the other.

They are extremely common as fossils, more than 5000 *species* of brachiopods having been described. The Brachiopoda have been subdivided into two divisions—1st, The Inarticulata, in which the shells are not hinged, but are simply held together by the muscles of the animal's body. The genera *Lingula, Obolella, Kutorgina, Discina,* and *Crania,* are well-known examples of inarticulate brachiopods, some of which, as *Lingula, Discina,* and *Crania,* are represented by species living in our present seas. 2nd, The Articulata, in which the valves of the shells are hinged together, usually by means of teeth and sockets. *Productus, Strophomena, Atrypa, Rhynchonella,* and *Terebratula* are genera of brachiopods possessing valves joined or hinged together by teeth and sockets.

In the Brachiopoda the two valves of the shell are of unequal sizes, but a line drawn down the centre is in the majority of cases a line of symmetry dividing the valves into two equal parts. It is noticeable, also, that the soft body of the animal itself is very small, and only occupies a small portion of the shell, the remainder of the space between the valves being filled by spiral calcareous processes. Lingula (which only differs from Lingulella in not having a central groove down one of its valves) is a very "persistent type", being found at the present day in the muddy Australian seas. The genus *Orthis,* in which the valves are almost equal, the hinge-line being shorter than the greatest width of the shell, first appears as the species *Orthis Carausii* in the Tremadoc Beds. *Orthis* is extremely common in the Ordovician and Silurian formations, but the form dies out in the Carboniferous strata. *Strophomena,* which is closely allied to *Orthis,* has its hinge-line forming the greatest width of the shell; it survived from Ordovician to Carboniferous times. The first known brachiopods, *Lingulella ferruginea* and *L. primæva,* occur in the Lower Cambrian strata. The *genera* of brachiopod shells which have survived from Palæozoic times right down to the present day include *Lingula, Rhynchonella, Terebratula,* &c.

Sub-kingdom VIII.—Mollusca.—The mollusca include all our ordinary shells. We must notice at least three classes.

1. *Lamellibranchs*—ordinary bivalve shells, such as the oyster, cockle, &c. The Lamellibranchs—unlike the brachiopods—have usually equivalve shells, *i.e.* the two valves are of the same size; but they are not equilateral—a line cannot be drawn which will divide the shell into two equal or symmetrical parts. In the lamellibranchs the animal completely fills up the space between the valves, and there are no spiral processes. The thick-shelled genus known as *Arca* extends from the Ordovician to recent times; while the handsomely-ornamented shell called *Trigonia* (so common in the Oolites) is still found living in the Australian seas. *Perna Mulleti*, from the Atherfield Clay, bears a resemblance to the Upper Cretaceous species *Inoceramus*, in that both are somewhat inequivalve, an exception to the general rule. The first or earliest fossil specimens of this class belong to the genera *Modiolopsis*, *Palæarca*, &c., and are found in the Tremadoc rocks (Upper Cambrian). The oldest British oyster is found in the Rhætic Beds; but in North America the same *genus* occurs as low down as the Devonian strata.

2. *Gasteropods*—having the shell all in one piece, and therefore called univalves. The first gasteropods (*Hyolithes* or *Theca*) are found in the Lower Cambrian strata.

The Gasteropods, or 'belly-footed' mollusca, possess a shell which is in one piece, and which is not divided into chambers. Gasteropods occur in enormous numbers in our present seas, and also in the fossil state. Among the early gasteropods we may mention the genera *Pleurotomaria*, which extends from the Tremadoc Slates of the Upper Cambrian right down to the present day; and *Bellerophon*, which extends from the Tremadoc Slates to the Permian. *Natica* is another ancient gasteropod which has survived from Silurian times down to the present day.

The great majority of the gasteropods are marine; remains of fresh-water and of terrestrial forms of gasteropods are, however, frequently found. The fresh-water gasteropods *Limnæa* and *Planorbis* occur plentifully as fossil forms in the Jurassic rocks, and are also abundant in our existing rivers and ponds.

The gasteropod land-shell genus named *Bulimus* extends from the Upper Cretaceous period to the present time.

3. *Cephalopods.*—This word means "head-footed" and is used to include such animals as the octopus, nautilus, and cuttle-fish, which have tentacles or "feelers" arranged round the head, by which they move about and seize their prey. The first known cephalopod belonged to the genus *Orthoceras*, and is found in Upper Cambrian rocks; this genus continued until the Trias, and hundreds of fossil species of Orthoceras have been found. The cephalopod called the *Nautilus* is a very long-lived genus, for it extends from Cambrian times to the present day. Both the *Nautilus* and another very important fossil cephalopod called the *Ammonite* possessed a chambered shell; *i.e.* one divided by transverse partitions, the animal inhabiting the last-formed and largest chamber. All the chambers were, however, connected by a tube called the siphuncle. Ammonites have been found of all sizes up to that of a cart-wheel. The first British ammonite is *A. planorbis* from the Lower Lias; but abroad ammonites have been found in Triassic and even in Permian rocks. The last ammonite is found in the Upper Cretaceous rocks, after which the genus became extinct. The *Belemnite* was a cephalopod with an internal shell, and was provided with an ink-bag by which it could obscure or darken the water in its neighbourhood in time of need, and so perchance escape from its enemies (see fig. 97). It ranges from the Lias to the Chalk inclusive, being thus specially characteristic of the Secondary or Mesozoic strata.

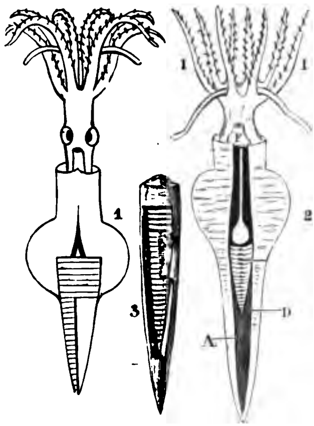


Fig. 97.—Belemnites (1, 2), showing the internal shell A D, and the head F, surrounded by the tentacles I I. In (3) the shell or "guard" is shown separately.

Classification of the Vertebrata.

Sub-kingdom IX.—Vertebrates.—The vertebrate animals are those which possess a bony skeleton, of which a vertebral column or backbone forms an important part. They include the most highly organized forms of animal life. It is usual to divide the Vertebrata into five classes—Fishes, Amphibia, Reptiles, Birds, and Mammals (see fig. 92).

Class 1.—Pisces or Fishes.—Fishes are vertebrates which throughout the whole of their life breathe by means of gills instead of lungs. The fishes of the Palæozoic rocks are distinguished by their unequally-lobed (heterocercal) tails, the backbone being prolonged into the upper lobe. Many of these old fishes were covered with a sort of armour of hard enamelled scales, whence they were known as *ganoids* (shining). The oldest British fish is *Scaphaspis Ludensis*, found in the Lower Ludlow Beds of Shropshire in 1859. In the Upper Ludlow Bone-bed the spines and scales of a fish called *Onchus* are found, which was a species of shark.

Fishes with equally-lobed (homocercal) tails first appear in the Trias, and they constitute the majority of the living species.

Class 2.—Amphibia.—The animals belonging to this class begin life as dwellers in the water, and they then possess gills like fishes; they soon, however, pass through a metamorphosis, proceed from the water to the land, and then possess lungs and have a general resemblance to reptiles. They include the frogs, toads, newts, &c. The first Amphibia appear in the Coal-measures (Carboniferous Formation); they belonged to the extinct *order* of the *Labyrinthodonts.*

Class 3.—Reptiles or Reptilia.—All true reptiles possess lungs throughout the whole of their existence. The first reptile is the rare *Proterosaurus* of the Permian Formation. But reptiles did not become common until Mesozoic times, when they attained such numbers and dimensions that this epoch of the earth's history has been styled the "Age of Reptiles". Turtles and tortoises first appear in the Oolite; but snakes not till the Eocene Period.

Class 4.—Aves or Birds.—The first bird (*Archæopteryx macrura*) is represented by two or three very perfect specimens which have been found in the Upper Oolite of Germany. It appears to have been about the size of a rook, but differs from all known birds in having two claws attached to its wings, in the back-bone being prolonged into a long lizard-like tail consisting of twenty distinct vertebræ to each of which a pair of quill-feathers was attached, and in having teeth like those of reptiles and fishes. In Britain the first remains of birds (belonging to the genus *Enaliornis*) occur in the "Cambridge Greensand", a stratum which may be considered as forming the base of the White Chalk. In the Eocene strata remains of birds begin to be common.

Class 5.—Mammals or Mammalia.—The mammals may be broadly defined as including all animals which suckle their young.

The mammals which are considered as of the lowest type or organization, are the *Marsupials* or pouched animals, such as the kangaroo, opossum, &c., which are now so characteristic of Australia and South America. The oldest known mammals belong to the order of marsupials, and are chiefly known by their fanged teeth and lower jaw-bones. The first mammal we meet with is *Microlestes antiquus*, whose tiny teeth occur in the Rhætic Bone-bed of England and of Germany.

We next find remains of mammals in the *Stonesfield Slate* (Great Oolite); they belong to the genera *Amphitherium*, *Phascolotherium*, and *Stereognathus*. They must have been of small size (varying from the size of a rat to that of a rabbit), and were marsupials allied to the opossum.

In the Upper Oolite (Purbeck Beds) many jaws of small marsupials have been found. The genera have been named *Spalacotherium*, *Plagiaulax*, *Triconodon*, &c.

No mammalian remains have been found in the English Cretaceous strata.

Describing the Mesozoic mammalia generally, Professor Owen writes:—They were "without exception low, insignificant in size and power, adapted for insect food, for preying

upon small lizards, or on the smaller and weaker members of their own low mammalian grade".

Of the order of *Ungulates* or hoofed mammals, the first specimens occur in the *Woolwich and Reading Beds*, and in the *London Clay* (Lower Eocene); and belong to the genera *Coryphodon*, *Hyracotherium*, &c.

The Oligocene strata of the Isle of Wight and of Hampshire have yielded the *Palæotherium*, which was allied to our rhinoceros, and also to the horse; and the *Dichobune*, which is our oldest ruminant, cud-chewer, or cow-like animal. The *Hipparion* was a form more nearly allied to our horse, which is found in the Miocene and Pliocene strata.

The elephants (or *Proboscidea*) appear first in the *Coralline Crag* (Pliocene), where teeth of the *Mastodon* occur. The first true elephant (*Elephas meridionalis*) appears in the Red Crag.

True Carnivores, Carnivorous, or flesh-eating mammals do not appear in the British Isles until Pliocene times, when we find teeth of the immense tiger, *Machairodus*, and also teeth of various species of cats, dogs, &c.

Lastly, Man—who is the most highly organized mammal—appears on the scene in the Pleistocene Period, being there represented mainly by his stone tools, which are more enduring and more lasting than the bones of his skeleton.

Life Zones in the Rocks, as defined by their Fossil Contents.—"A *zone* may be defined as a stratum or set of strata characterized by an organism, which may or may not be the chief form of that zone, but which is nearly or entirely confined to it, and from which it takes its name; it may be of considerable thickness, and may contain material of different composition in different parts of its extent."

The use of different forms of fossils for determining the successive horizons or relative order of succession of the geological strata can only be ascertained by working out the vertical ranges of such fossils in the strata. Some fossils have a much more extended vertical range than others which are closely allied to them; for example, in the Llandovery Beds of the Lake district, the graptolite *Monograptus gregarius* ranges

up and down through more than thirty feet of rock; while its cousin *Monograptus argenteus* is there limited to a zone only eight inches in thickness of the same set of strata. The special value of fossil forms which have such a *limited* vertical range is obvious. The same species found in another region or country would mark very precisely the horizon or position of the stratum in which it occurred. The fossils in the two different horizontal positions or localities must be in the same geological zone, and must have lived at or about the same time. Thus although the rocks in one locality consisted of sandstones, and in the other locality of shales, still, if they each contained *M. gregarius* and *M. argenteus*, they would both be referred by geologists to the Llandovery Beds; for these two graptolites mark life-zones which occur only in that formation.

In the same way the *Olenellus zone* (marked by the presence of trilobites of that genus) enables us to fix the upper limit of the Pre-Cambrian Rocks, for this zone forms the base of the Cambrian Formation, so that all below it must be "Pre-Cambrian".

The Stockdale Shales (Ordovician) of the Lake district are divisible into nine graptolitic zones, and are extremely thin; but elsewhere they are represented by enormous deposits, often thousands of feet in thickness, as near Girvan (south of Scotland) and in Central Wales. But the various graptolitic zones of the Stockdale Shales are clearly traceable in these expanded deposits, as at Girvan where each zone is of great thickness; and every species of graptolite occurs in precisely the same order in each locality.

In Bohemia, the Lower Ludlow Rocks may be termed the zone of *Monograptus colonus*, and this zone is there comparatively thin. The same zone, characterized of course by the same species of fossil, is in the English Lake District upwards of 10,000 feet in thickness.

Using the term "zone" in its widest sense, we often find zones characterized by a particular genus having a very extended horizontal or geographical range. Thus the zone of the graptolite known as *Bryograptus* has been recognized in Britain, in

Scandinavia, and in America; and that of *Dictyograptus* in Britain, Belgium, Russia, Scandinavia, and America.

Table of the Stratified Rocks showing the order of Succession of the Fossiliferous Strata which occur in the British Isles.

FORMATION.		SUBDIVISIONS.	NATURE.
RECENT OR POST-GLACIAL.		Alluvium, ...	Freshwater.
		River Terraces, ...	”
		Submerged Forests, ...	Terrestrial.
		Peat Beds, ...	”
		Certain Cavern deposits, ...	”
		Tufaceous deposits of springs, ...	Freshwater.
		Implements, &c., of Neolithic Man,	Terrestrial.
		Raised Beaches, ...	Marine.
		Beach deposits, ...	”
PLEISTOCENE OR GLACIAL.		Boulders, ...	(Chiefly produced by ice-action.)
		Eskers, ...	
		Glacial Gravels, ...	
		Till and Boulder Clays, ...	
		Certain Cavern deposits, ...	
		Brick-earths, ...	
		Implements of Palæolithic Man, ...	
PLIOCENE.	*Newer.*	Cromer Forest Bed.Group, ...	Estuarine and Freshwater.
		Norwich Crag, ...	Marine.
		Red Crag, ...	
	Older.	White or Coralline Crag, ...	
		St. Erth Beds, ...	
		Lenham Sands, ...	
MIOCENE.		Wanting or absent in the British Isles, so that a considerable break in the succession of the British strata occurs here.	
OLIGOCENE.		Hempstead (or Hamstead) Beds,	The Fluvio-Marine Series.
		Bembridge Beds, ...	
		Osborne Beds, ...	
		Headon Beds, ...	
EOCENE		Bagshot Beds, including the Barton, Bracklesham, Bovey Tracey, &c., Beds, ...	Marine (but Freshwater locally).
		London Clay, and Bognor Beds, ...	Marine.
		Oldhaven Beds, ...	
		Woolwich and Reading Beds, ...	Freshwater to Marine.
		Thanet Sands, ...	Marine.

(Great break or interval of time occurs here.)

	Formation.	Subdivisions.	Nature.
Cretaceous.	*Upper Cretaceous.*	Upper White Chalk (with flints), ...	Marine.
		Lower White Chalk (without flints),	
		Chalk Marl or Gray Chalk, ...	
		Chloritic Marl, ...	
		Upper Greensand, ...	
		Gault, ...	
	Neocomian or Lower Cretaceous.	Lower Greensand and Upper Speeton Clay, ...	Marine.
		Lower Speeton Clay (Yorkshire), ...	
		Wealden Beds: Weald Clay, ...	Estuarine.
		Wealden Beds: Hastings Sands, ...	

(Break or interval of time occurs here.)

	Formation.	Subdivisions.	Nature.
Jurassic. Oolitic Formation.	*Upper Oolite.*	Purbeck Beds, ...	Freshwater and Terrestrial.
		Portland Beds, ...	Marine.
		Kimeridge Clay, ...	
	Middle Oolite.	Coral Rag, ...	
		Oxford Clay, ...	
		Kellaways Rock, ...	
	Lower Oolite. — *Great Oolite.*	Cornbrash, ...	Marine in south and centre of England.
		Forest Marble, ...	
		Bath Oolite, ...	
		Stonesfield Slate, ...	
		Fuller's Earth.	
	Lower Oolite. — *Inferior Oolite.*	Lincolnshire Oolite, ...	Estuarine in centre of England, Yorkshire, and Scotland.
		Collyweston Slate, ...	
		Northampton Sands, ...	
		Midford Sands (passage beds), ...	
Jurassic.	Liassic Formation.	Upper Lias, ...	Marine.
		Middle Lias or Marlstone, ...	
		Lower Lias, ...	
		Rhætic or Penarth Beds (beds of passage), ...	
	Triassic Formation or "Trias", or "New Red Sandstone".	Upper Keuper Marls, ...	Formed in very salt lakes and inland seas.
		Lower Keuper Sandstones, ...	
		(Place of the Muschelkalk.)	
		Bunter Sandstone, ...	
		Bunter Conglomerate, ...	

(Great break or interval of time occurs here.)

FORMATION.		SUBDIVISIONS.	NATURE.
PERMIAN FORMATION.		Upper Red Sandstones and Clays, ... Magnesian Limestone, ... Marl Slate, ... Lower Red Marls and Sandstones, ... Breccias (or 'Brockram'), ...	Deposited in inland seas and salt lakes (some volcanic action in Scotland).
		(Break or interval of time unrepresented by any deposits in the British Isles occurs here.)	
CARBONIFEROUS FORMATION.		Coal-Measures, ...	Mainly Terrestrial.
		Millstone Grit, ... Yoredale Beds, ... Carboniferous Limestone and Shales, Culm Measures (Devon), ... Calciferous Sandstones (Scotland), ...	Mainly Marine. (Volcanoes active in Scotland.)
		(Break or interval occurs here.)	
OLD RED SANDSTONE AND DEVONIAN FORMATIONS.	Upper Old Red or Brownstone" Series.	Upper Devonian, or Barnstaple and Petherwyn Series.	Old Red Sandstone formed in fresh-water lakes. (Volcanic action frequent.)
		Middle Devonian, or Ilfracombe, Plymouth and Torquay Series.	Devonian, Marine. (Some volcanic action.)
	Lower Old Red or "Cornstone" Series.	Lower Devonian, or Lynton Group.	
		(Break occurs here.)	
SILURIAN FORMATION.	*Ludlow Series.*	Ledbury Slates, } Beds of ... Downton Sandstones, } passage, ... Upper Ludlow Beds, ... Ludlow or Aymestry Limestone, ... Lower Ludlow Shales, ...	Marine.
	Wenlock Series.	Wenlock Limestone, ... Wenlock Shales, ... Woolhope Limestone, ...	
	May Hill Series.	Upper Llandovery, or May Hill Sandstone, ... Lower Llandovery Beds (=beds of passage), ...	
		(Break occurs here.)	
ORDOVICIAN FORMATION.		Bala and Caradoc Group, ... Llandeilo Series, ... Arenig or Stiper-stones Series, ...	Marine (many volcanic outbursts).
		(Break or interval of time occurs here.)	

	FORMATION.	SUBDIVISIONS.	NATURE.
CAMBRIAN FORMATION.	*Upper Cambrian or* Olenus *Zone.*	Durness Limestone (Scotland), ... Tremadoc Slates, ... Shineton Shales, ... Stockingford and Dosthill Shales, ... Lingula Flags, ...	Marine.
	Middle Cambrian or Paradoxides *Zone.*	Menevian Beds, ... Harlech Grits and Llanberis Slates,	Marine.
	Lower Cambrian or Olenellus *Zone.*	Hollybush and Comley Sandstones, Fucoid Beds (Scotland), ... Hartshill, Lickey, and Wrekin Quartzites, ...	Marine.

(Great break or interval of time occurs here.)

FORMATION.	SUBDIVISIONS.	NATURE.
PRE-CAMBRIAN OR ARCHÆAN FORMATION.	Torridonian Sandstones (Scotland), Longmyndian Flags (Shropshire), ... Charnwood Forest Slates, ... Barnt Green (Lickey) Ashes, ... Caldecote (Nuneaton) Ashes, ... Uriconian Rhyolites (Shropshire), ... Malvernian Schists (Malvern Hills), Anglesey or Monian Schists, ... Pre-Cambrians of St. David's (S. Wales), ... Dalradian or Highland Schists (Scotland), ... Lewisian Gneiss (Scotland), ... Laurentian Rocks (Canada), ...	Marine (mostly volcanic, and usually highly metamorphosed).

PART III.

HISTORICAL OR STRATIGRAPHICAL GEOLOGY.

SECTION J.—THE EOZOIC SERIES.

CHAPTER XX.

THE ARCHÆAN OR PRE-CAMBRIAN FORMATION.

General Description of the Oldest-known Strata.—The men who studied geology in the early part of this century, named the old rocks of Wales, the West of England and the Highlands of Scotland, the PRIMARY STRATA, because they believed them to be the earliest or first-formed rocks.

Later researches showed that these rocks could not have been the "first-formed", because they are themselves clearly composed of fragments of older, pre-existing rocks; and the name PALÆOZOIC was then proposed for them, because they included the fossil remains of *ancient life*. These Palæozoic rocks are described in Chapters XXI. to XXVI.

In still more recent times the researches of modern geologists have brought to light a great series of *bottom rocks*—called Laurentian, Pre-Cambrian, or Archæan—of which the early geologists did not suspect the existence. These bottom rocks are sometimes classed with the Palæozoic rocks; but it is now generally considered preferable to put them in a class of their own, and to call them either AZOIC (*a*, without life; and *zoe*, life) or EOZOIC (*eos*, the dawn; and *zoe*, life), according as it may ultimately be proved whether they contain a group of true fossils or not, a point which is at present not fully ascertained.

Granite not the Oldest Rock.—The early geologists considered granite as the oldest of all the rocks. But we now

know that granite may be of any age; for it is an igneous rock, and the volcanic forces, to which the formation of all such rocks is due, have been continuously at work during all known stages of the earth's history. An igneous rock must be *newer* than any rock which it invades, breaks through, or alters. Judged by this test the granites of Germany, the Vosges Mountains, and Christiania are of Silurian age. The granite of Dartmoor and of other granitic bosses in Devon and Cornwall is *later* than the Carboniferous epoch. Some granites in the Alps were intruded after the deposition of the Liassic strata; while in Chili, Jamaica, &c., there are granites which can even be shown to belong to the Tertiary Period.

The Oldest-known Stratified Rocks.—To find the oldest rocks we must ascertain which naturally lie at the bottom, or underneath all the others; for of any two beds of rock lying in their natural positions the one below must have been the first formed. Judged by this test the oldest rocks of Great Britain are certain gneissic, schistose, and volcanic strata which crop out in the north-west of Scotland, and which form the Outer Hebrides: they are also known in Anglesea, and in the extreme west of Wales at St. David's. Similar strata form the Malvern Hills of Worcestershire, the Longmynd Hills, Caer Caradoc and the Wrekin Hills of Shropshire, and the hilly district of Charnwood Forest in Leicestershire (see fig. 98).

Fig. 98.—Section from West to East showing the Succession and Genera Arrangement of the Stratified Rocks in Wales and England. 1, Archæan and Cambrian; 2, Ordovician and Silurian; 3, Old Red Sandstone; 4, Mountain Limestone; 5, Millstone Grit; 6, Coal-measures and Permian; 7, Trias; 8, Lias; 9, Oolites; 10, Cretaceous; 11, Tertiary and Quaternary.

Names which have been given to the Oldest or Bottom Rocks.—For a long time the *Cambrian* rocks of Wales were believed to be the oldest upon the face of the earth. But in the year 1854 Sir William Logan, who was then engaged in mapping the rocks of Canada,

found along the river St. Lawrence an enormous thickness (30,000 feet or more) of gneiss, quartzite, schist, limestone, &c.: these rocks *underlying*—and being therefore older than—the Cambrian strata, which are also well developed in that country. To these "bottom rocks" Logan gave the name of *Laurentian*.

For some time afterwards the same name was also applied to the somewhat similar rocks which were found to underlie the Cambrian Formation in Britain. But it was felt to be safer to give the English rocks a more general name, and they are therefore now usually called either PRE-CAMBRIAN—which simply means "older than the Cambrian strata"—or ARCHÆAN (from the Gr. *archaios*, ancient), the latter term having been first proposed by Dana, the American geologist, in 1874. They were also known to the early geologists as the "Primitive" strata.

In Canada the total thickness of the Laurentian, Pre-Cambrian, or Archæan Rocks is now estimated at 50,000 feet. In Britain it is nothing like so great as this (though still considerable); but the thickness of these extremely old and altered rocks is a very difficult matter to determine, for all signs of the original stratification in them have often been destroyed, and the rocks have been so bent and folded that it is possible the same beds may have been measured more than once in the same section.

In the British Isles, the Pre-Cambrian rocks are best displayed in the North-west Highlands of Scotland. They there consist of the "Lewisian Gneiss", which comprises an intricate complex of rocks among which may be mentioned mica and quartz schists, hornblende and chlorite-schists, granitites[1], and crystalline marbles. Penetrating these rocks are intrusive dykes and sills of dolerite, gabbro, granite, and pegmatite. The upper 10,000 feet of the Pre-Cambrian rocks of this area consist of sedimentary and comparatively unmetamorphosed grits and sandstones, which are collectively known as the Torridon Sandstone. The base of this Torridon Sandstone is made up of an angular breccia, in which are fragments derived from

[1] *Granitite* is the name given to basic granites containing some plagioclase felspar and biotite-mica, in addition to the ordinary constituents of granite.

the underlying "Lewisian Gneiss"; in addition there are many fragments of jasper, chert, and rhyolite in this basal breccia, the origin of which is unknown for they do not occur in the visible underlying Archæan rocks. Worm-casts have been noticed in the upper beds of the Torridon Sandstone, together with shaly bands which contain meagre and obscure indications of organisms.

The Archæan Rocks not the First-formed.—The Archæan strata are not the rocks which were the first-formed upon the face of the earth. They are only *the oldest of which we have any knowledge.* Rocks must have existed before them, out of whose debris the strata we call Archæan were formed. But of these earlier rocks no trace has as yet been detected.

Metamorphic Character of the Archæan or Pre-Cambrian Rocks.—It is evident that—other things being equal—the *older* a rock is, the more likely it is to have been *altered* since its original formation. Accordingly we find that most of the Archæan strata are more or less metamorphosed; many of them are distinctly crystalline and foliated, being now in the state of gneiss and mica-schist; others are altered volcanic tuffs and lavas; while occasional beds of crystalline limestone and quartzite occur.

Probably a very large proportion of the Archæan strata is of volcanic origin.

The Oldest-known Fossil?—If the Archæan strata were mostly formed in volcanic districts and by volcanic agencies, we cannot expect them to contain many traces of life—many *fossils.* Nor do they. Yet diligent and long-continued search has yielded some evidence of the existence of animals and plants at even that remote epoch.

About the year 1858 Sir W. E. Logan noticed, and in 1865 Sir J. W. Dawson of Montreal described, certain coral-like masses in the Laurentian limestones of Canada, as a compound species of *Foraminifera.* To this ancient lowly-organized animal, Dawson gave the name of *Eozoon canadense* (the "dawn animal of Canada"), and if its organic nature be granted it is the oldest known fossil.

It occurs in rounded masses, which may be several feet in diameter, and which consist of crystalline whitish limestone (calcite) traversed by green streaks of serpentine. The latter mineral is supposed to have filled up the tubes and cavities left by the decaying of the soft parts of the animal. It is believed that the *Eozoon* grew in masses on the ocean floor—somewhat as the coral polyp does now—building up limestone reefs (see fig. 99).

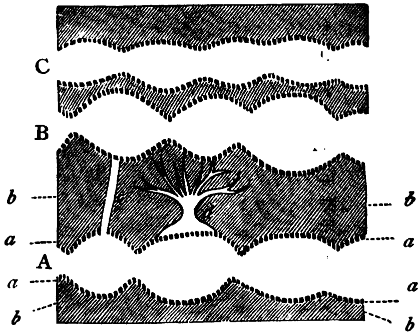


Fig. 99.—*Eozoon canadense.* A thin slice of Laurentian limestone magnified, showing the original skeleton (composed of carbonate of lime) at *b b*; at A, B, C are shown passages or chambers occupied by the soft parts of the animal (now filled with green serpentine). Two of these chambers are connected at *c*. At *a*, *a* we see the walls of the chambers; and at *d* a canal system.

By many eminent workers, however, the organic origin of the *Eozoon* is denied; and it is affirmed by these authorities to be a purely inorganic and mineral structure—in other words, a *pseudo-fossil.* This view has gained much ground during the last few years. The Archæan rocks of Britain contain no massive beds of limestone like those of Canada; so that no traces of *Eozoon* have as yet been detected in this country.

Other Traces of Life in Archæan Rocks.—The Laurentian rocks of Canada contain great quantities of *graphite,* or nearly pure carbon; and its presence is considered to be strong evidence of the existence of *plants* during that remote period. The very limestone beds themselves, if not formed by the *Eozoon,* are possibly due to the action of animal life in some shape or form; for nearly all limestones are "organically formed rocks".

Thick beds of iron ore are also found in the Laurentians of Canada, and these, it is thought, may have been deposited from water by the chemical action of decaying vegetable matter.

Use of the Term "Eozoic".—The term EOZOIC (*eos*, the dawn; and *zoe*, life) is sometimes applied to the Archæan strata, because in them we possibly have "the dawn of life"; or the first, though scanty, evidences of the existence of life upon our planet. The early geologists called these rocks *Azoic* (*a*, without; and *zoe*, life) because they believed them to contain no traces of life.

Economic Products.—The Archæan rocks of the British Isles contain but few minerals of importance. The granites and syenites furnish good hard road-metal, and they will also usually "cleave" into square blocks or "setts", used for street-paving and for kerb-stones. Marble and serpentine are ornamental stones which are quarried for mantel-pieces, &c. Gold occurs sparingly in some of the quartz veins.

The Torridon Sandstone (10,000 ft. thick) of the N.W. of Scotland is probably intermediate in age between the Archæan proper and the Cambrian Formations.

SECTION K.—THE PALÆOZOIC OR PRIMARY SERIES.

CHAPTER XXI.

Setting aside the Archæan strata, we have above them a thickness of about 85,000 feet (or 16 miles) of stratified rocks to which the name *Palæozoic* may be given. This enormous

TABLE OF THE PALÆOZOIC FORMATIONS.

FORMATION.	Max. Thickness in Feet.
Permian or Dyas,................................	3,000
Carboniferous,................................	18,000
Old Red Sandstone or Devonian, ...	20,000
Silurian,................................	6,000
Ordovician,................................	20,000
Cambrian,................................	18,000
Total,................................	85,000

mass is usually divided into the six *formations* named in the table on p. 205, of which the maximum thickness is in each case given. Of the six great geological divisions enumerated in this table, the three lower have a general resemblance, and may be grouped together under the title of *Lower Palæozoic*; as also may the three upper, as the *Upper Palæozoic.*

THE CAMBRIAN FORMATION.

Origin of the Name Cambrian.—Up to the year 1830, or thereabouts, geologists considered the Lower Palæozoic strata to be such a barren, complex, difficult, and uninteresting set of rocks, that they regarded their study, classification, and mapping as an impossible, or all but impossible, work.

But in 1831 Professor Adam Sedgwick (of Cambridge University) began the diligent study of these old rocks in North Wales, and he was able to announce in 1836 that he had determined the general order of succession in that district of a certain ancient group of slaty, gritty, and flaggy strata; for which he proposed the name of **Cambrian**, from *Cambria*, the ancient name of North Wales.

Subdivisions of the Cambrian Formation.—Further work by Sedgwick, and the researches of geologists since his time (he died in 1873, aged eighty-eight), have shown that the Cambrian rocks of Britain *average* about twelve thousand feet in total thickness where they are best developed (in Wales), and that the following subdivisions may be made in them:—

		Average thickness in feet.
UPPER CAMBRIAN	Tremadoc Slates, and Durness Limestones	1500
	Lingula Flags	3000
MIDDLE CAMBRIAN	Menevian Beds	500
	Harlech Grits and Llanberis Slates	6000
LOWER CAMBRIAN	Caerfai Beds (St. David's)	1500
	Hollybush and Comley Sandstones Fucoid Beds (Scotland) Hartshill and Lickey Quartzites	1000

Unconformity between the Cambrian and the Archæan Strata.—Wherever the *junction* between the Ar-

chæan and the Cambrian Formations is exposed in the British Isles the newer rocks are seen to rest *unconformably* upon the older. For if the want of parallelism between the beds is not evident in the actual section examined, it becomes very obvious when traced over an extent of country. Moreover, the basement bed of the Cambrian is usually a thick bed of conglomerate, containing large fragments of the Archæan or Pre-Cambrian rocks.

The Lower Cambrian or Olenellus Beds.—In the North-west Highlands of Scotland the base of the Lower Cambrian Formation is well defined. It there rests unconformably upon the Torridon Sandstone, which is of Pre-Cambrian age. The Lower Cambrian strata in this region consist of false-bedded grits and arenaceous quartzites, with brecciated conglomerates at the base; the total thickness of this Lower Cambrian deposit being here about 500 feet.

The upper half of the arenaceous quartzite is known as the "Pipe-rock", owing to the number of vertical pipes of the annelid *Scolithus* with which it is permeated. Above and resting upon the quartzite come the so-called "Fucoid" beds, from 40 to 50 feet thick, and consisting of a matted network of the flattened sandy excrement of worms. Above this is the "Serpulite", or "Salterella Grit", some 30 feet in thickness, in which is found the tubular pteropod shell *Salterella*. Interstratified with the Salterella Grits are two thin bands of dark-blue shale which have yielded the remains of the oldest known fauna of Britain; including *Olenellus Lapworthi*, *Hyolithes*, *Salterella pulchella*, &c. The quartzite, "Fucoid" beds, and Salterella Grit all belong to and here form the lowest horizon of the Cambrian System.

Resting upon the Salterella Grit are a series of crystalline limestones known as the Durness Series. These limestones are from 1300 to 1500 feet in thickness, and have yielded such fossils as *Nautilus* and *Orthoceras*, *Maclurea* and *Pleurotomaria*, and Sponges. From their fossil contents the Durness limestones are probably of Upper Cambrian Age.

The Midland or Basal Cambrian Quartzites.—In the Midland

Counties of England a bed of quartzite is well displayed in the Hartshill Range of Warwickshire (where its thickness is about 1000 feet), the Lower Lickey Hills of Worcestershire, and on the flanks of the Wrekin in Shropshire (where its thickness does not exceed 200 feet). The rock is much jointed, and in Triassic times it constituted one of the principal sources of the quartzite pebbles of which such great numbers are found in the Bunter Conglomerate. It rests in all the localities named upon Pre-Cambrian volcanic rocks; and—with the exception of a worm-burrow or two—the great mass of this basal quartzite is not known to contain any fossils.

The Nuneaton, Comley, and Hollybush Sandstones.—The basal Cambrian quartzite of the Midlands thins, as we have seen, as we follow it westward, and it is not known west of the line of Pre-Cambrian volcanic rocks which extends from Caer Caradoc to the Wrekin. But on the western slope of the Malvern Hills we find the Hollybush Sandstone (so named from the "Hollybush Valley" in which it crops out), about 400 feet in thickness and containing fossils of Lower Cambrian age. In the little quarry of Comley, on the slope of Caer Caradoc, Prof. C. Lapworth found in the year 1885 the trilobite *Olenellus Callavei*, which proved at once the Lower Cambrian age of the deposit. And in sandy beds forming the top, or resting upon the Hartshill basal Quartzite near Nuneaton, Prof. Lapworth has quite lately proved the presence of the same Lower Cambrian fauna, the pteropod shell *Hyolithes* being here the principal fossil.

Fig. 100 is from a photograph of a quarry in the ridge of quartzite north-west of Nuneaton in Warwickshire, and which is termed the Hartshill Range. This quartzite was formerly regarded as metamorphosed Millstone Grit; but as it is underlain by volcanic ashes of Archæan age, and is overlaid by purple and black shales containing such Cambrian fossils as *Agnostus*, *Kutorgina*, and *Lingulella*, it is evident that the quartzite must be a Lower Cambrian deposit.

Traversing this Cambrian quartzite are numerous more or

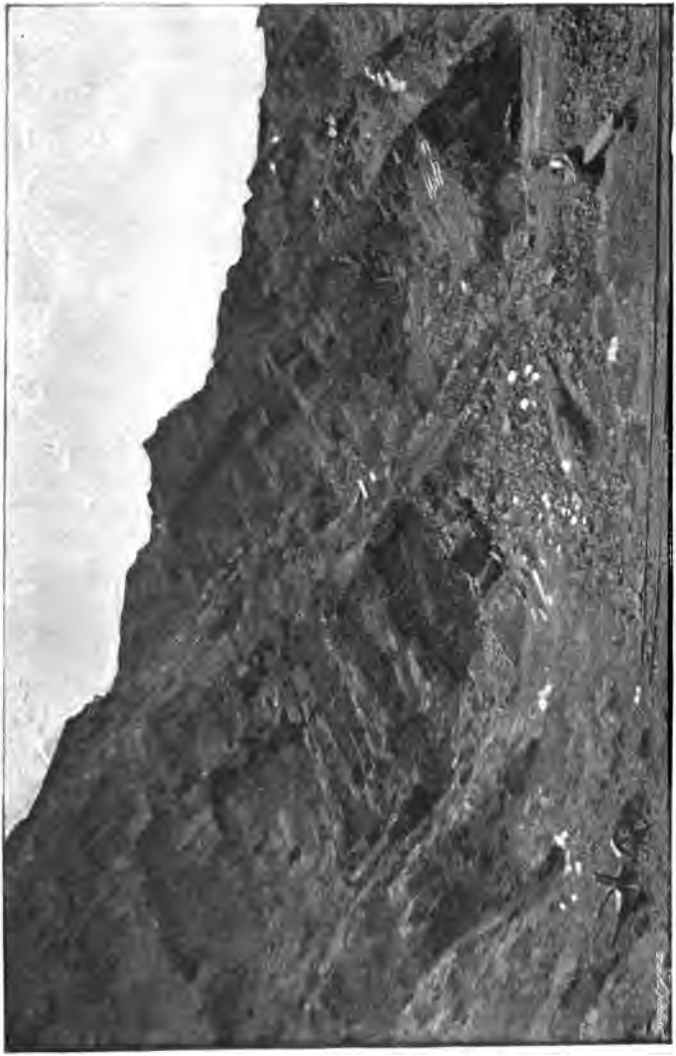


Fig. 100.—Lower Cambrian Quartzites near Nuneaton, Warwickshire.

less vertical wall-like dykes of dark diorite (see fig. 101). These dykes are of course of more recent date than the quartzites which they intrude upon, and they illustrate how an igneous rock, although holocrystalline and plutonic, may be intruded into sedimentary deposits in a manner similar to volcanic rocks.

The Cambrian quartzites of Nuneaton and Hartshill dip at an angle of 45° to the west. They are much jointed, breaking into cubical blocks of all sizes; and, owing to their hardness, are much quarried for road-metal.

Dr. H. Hicks states that the lowest Cambrian strata (named the "Caerfai Group") discovered by him at St. David's in South Wales, contain fragments of *Olenellus*, along with a small brachiopod (*Lingulella primæva*), &c.

Lower Cambrian Rocks in America and Sweden.—At the present time our knowledge of this very ancient Lower Cambrian fauna is derived principally from the published results of foreign geologists. In the United States, and in Sweden, about 200 species of fossils have so far been obtained from these the oldest undisputed fossiliferous strata.

But although the number of species is comparatively few, yet the fossils are spread over nearly the whole of the divisions which constitute the Invertebrata. Thus Mr. C. D. Walcott enumerates from the Lower Cambrian or Olenellus Zone of the United States representatives of—

(1) Spongida.	(6) Brachiopoda.
(2) Hydrozoa.	(7) Lamellibranchiata.
(3) Actinozoa.	(8) Gasteropoda.
(4) Echinodermata.	(9) Pteropoda.
(5) Annelida.	(10) Crustacea.

(11) Trilobita.

Origin of the Lower Cambrian Fauna.—We see that in Lower Cambrian times not only were there many species of animals inhabiting the seas, but that these animals were of very distinct and diverse kinds, representing nearly all the subdivisions of the Invertebrates.

Now the doctrine of evolution—which in some form or other

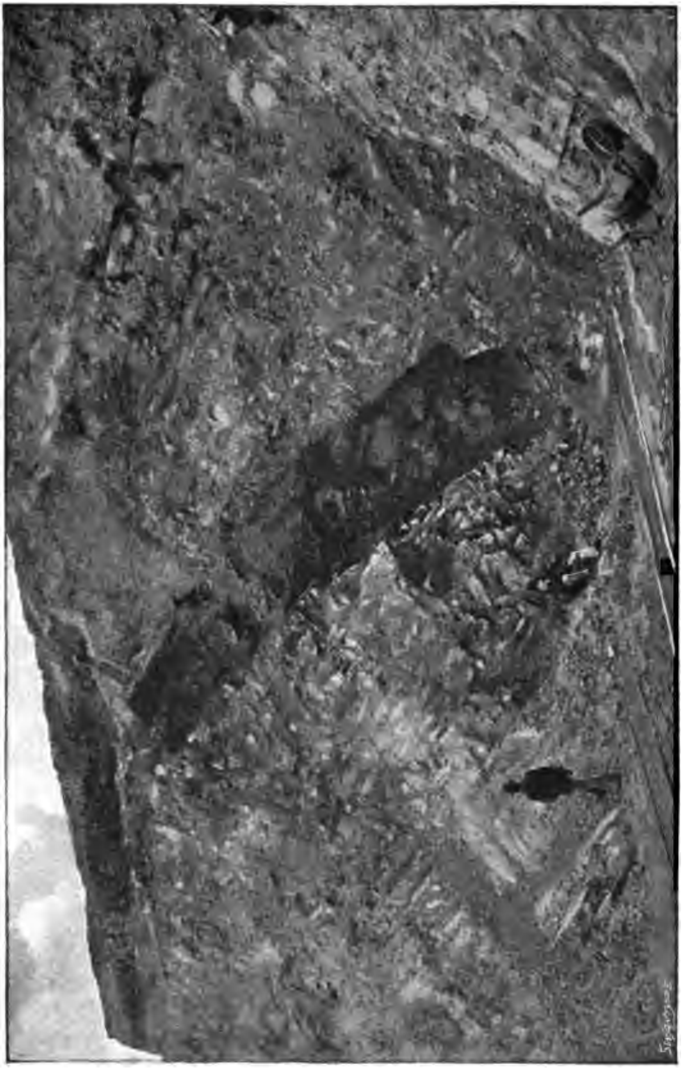


Fig. 101.—Dyke of Diorite cutting across Lower Cambrian Quartzites, Hartshill, Warwickshire.

is now all but universally accepted—teaches us that such a collection of diverse beings could not come into existence all at once; but that such differences in the animal creation must be the result of slow and long-continued changes and modifications. Life must therefore have existed upon the earth for long ages before the Cambrian rocks were formed, and of such pre-existing forms of life it cannot be doubted but that the Pre-Cambrian strata will yet give us much evidence. These Pre-Cambrian rocks are being diligently searched, and already some traces of fossils are beginning to reward the seekers.

Yet it seems unlikely that we shall ever know *much* about the living beings from whom the Cambrian fauna descended. For one thing, the Pre-Cambrian strata have been, for the most part, so altered and metamorphosed, that the greater part of the fossils which they may once have contained must have been obliterated.

And we must always remember that it is only the *hard parts* of animals which are capable of preservation in the rocks. Now in the Pre-Cambrian ages it is probable that the animals had few or no hard parts, but were mainly soft-bodied or membranous. In such cases we could not expect to find them preserved—as fossils—in the Pre-Cambrian rocks.

The Middle Cambrian or Paradoxides Beds.—In the neighbourhood of Bangor and Llanberis the basement conglomerate of the Cambrian is overlain by thick grits and slates, which are also well developed near Harlech, further south. These rocks contain very few fossils in North Wales; but at St. David's in South Wales Dr. Hicks found in strata of the same age several species of trilobites, a sponge, six brachiopod shells, &c. These rocks are known as the *Harlech and Llanberis Beds.* The surfaces of the sandy layers are often marked with worm-tracks, ripples, and rain-pittings. Of the trilobites we may name *Paradoxides aurora* as a characteristic species; and of the brachiopods, *Lingulella ferruginea.* Dipping to the east, the Harlech Beds pass under newer rocks, and they do not appear to come to the surface again in this direction.

Certain grits and flagstones which occur in Wicklow in the south-east of Ireland, are probably also of Cambrian age. The Wicklow Beds are well exposed at Bray Head, where they contain some curious plant-like markings to which the name of *Oldhamia* has been given (see fig. 77 *c*).

Resting on the comparatively barren Harlech Beds we find about 500 feet of dark slates and flags, which at St. David's yielded a well-marked fauna (52 species of trilobites, brachiopods, &c.) to the search of Dr. Hicks. He named this subdivision the *Menevian Beds* (from *Menevia*, the ancient name of St. David's). The large trilobite named *Paradoxides Davidis* is a characteristic Menevian fossil.

The Upper Cambrian or Olenus Beds.—In both North and South Wales the Upper Cambrian strata repose conformably upon the Middle Cambrian beds. The *Lingula Flags* are so named from their most abundant and characteristic fossil—the brachiopod shell *Lingulella Davisii*, discovered by Mr. E. Davis in 1846. In North-west Wales they are dark-blue and black slates, well seen round Maentwrog and Dolgelly. They contain the curious shrimp-like fossil crustacean *Hymenocaris vermicauda*, and also many species of trilobites, of which the genera *Agnostus* and *Olenus* are very characteristic.

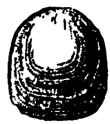


Fig. 102.—*Lingulella Davisii* (or Davis's Lingulella); an Upper Cambrian brachiopod shell.

The *Tremadoc Slates*, which form the uppermost member of the Cambrian Formation, are well developed round the little town of Tremadoc in North Wales. In beds of the same age, at Ramsey Island (Pembrokeshire), the first British fossil bivalve shells appear. Of the many species of fine trilobites which occur in the Tremadoc Slates, *Angelina Sedgwickii* is perhaps the best known.

In Central England the Upper Cambrian strata consist of shales which are exposed at Shineton in Shropshire; and at Dosthill, and also east of Stockingford in Warwickshire.

At Durness, in the North-west Highlands of Scotland, limestones of the Upper Cambrian age occur, which are character-

ized by such fossils as the chambered shell called *Orthoceras* and the gasteropod shell *Maclurea*. No Upper Cambrian rocks are known in Ireland.

Economic Products.—The Cambrian rocks contain, in the Lingula Flags and near their base, veins of gold-bearing quartz which have long been worked near Dolgelly, in Wales. Gold also occurs in Cambrian strata in Wicklow (Ireland), and in Sutherlandshire (Scotland). Veins of silver and of iron-ore also occur; but more important than these are the excellent beds of roofing slate, which at Llanberis and elsewhere in North Wales give employment to many thousands of quarry-men.

Summary of the Cambrian Formation.—In the Cambrian strata we get for the first time certain and definite evidence of the existence of life on the earth, and of the prevalence of a state of things similar to that which now exists. The Cambrian Formation can be divided into three groups, the lowest of which is characterized by trilobites of the genus *Olenellus*; above which come strata with *Paradoxides*; while in the upper beds *Olenus* is the chief trilobitic form.

The Cambrian rocks are old sands and muds—now hardened and altered into quartzites, sandstones, shales, slates, &c.—which were deposited in a deep sea which then stretched over Wales and the adjoining parts of central England, and which extended westward to the Irish coast at Wicklow and Wexford, and northwards—perhaps as a long gulf—up the west of Scotland to Loch Torridon and Loch Eriboll.

Of fossils the Cambrian rocks of Britain have yielded, so far, about 75 genera and 200 species. By far the most numerous and remarkable of the forms of life found in the Cambrian strata are the extinct crustaceans called *Trilobites*.

CHAPTER XXII.

THE ORDOVICIAN OR LOWER SILURIAN FORMATION.

The Cambro-Silurian Controversy.—During the years between 1831 and 1835, while Sedgwick was occupied in studying the rocks of North Wales, another geologist, Mr. (afterwards Sir) Roderick Murchison—was engaged in the examination of the strata which occupy the south-east of Wales and the adjoining border counties of England. To these rocks Murchison gave, in 1835, the name of SILURIAN, from the ancient British tribe of the *Silures*, who inhabited that part of the country when the Romans invaded Britain.

Murchison, during succeeding years, studied the strata in *downward* succession; and as he found somewhat similar fossils in bed after bed, he added by degrees all these lower rocks to his Silurian system, until at last he included in it all the strata from the Ludlow Beds above to the Lingula Flags below. As Murchison became the head of the Government Geological Survey, his plan was naturally adopted by the officers of that survey, and the geological maps they prepared were coloured and described accordingly.

In the meantime Sedgwick had been working *upwards*, and he declared that his Cambrian Formation must naturally include all the strata from the Harlech Beds below, up to and including the Bala or Caradoc beds above.

Thus, according to Murchison, the *middle part* of the great system of ancient stratified rocks discovered by the joint labours of the two geologists, belonged to the Silurian Formation; while Sedgwick claimed it for the Cambrian. Thus the "Upper Cambrian" of Sedgwick included the same strata as the "Lower Silurian" of Murchison.

Ever since 1846 the question has been in dispute, some writers taking one side and some the other.

The best plan, perhaps, is that proposed by Professor Lapworth in 1879, viz., to separate the strata in dispute from both

the Cambrian and the Silurian Formations, and to call them ORDOVICIAN (from the ancient British tribe of the *Ordovices* who formerly inhabited those parts of North Wales where these rocks are best displayed).

Subdivisions of the Ordovician Rocks.—Owing to the occurrence in some localities of volcanic rock-masses which are absent in others, the total thickness of the Ordovicians varies from 10,000 to 20,000 feet. Perhaps 12,000 feet is the average thickness.

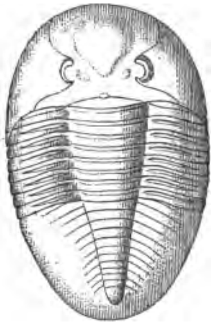


Fig. 103.—*Asaphus tyrannus*; a characteristic Ordovician (*Llandeilo*) trilobite.

At the base, resting conformably on the Tremadoc Slates, we have the *Arenig Series*, whose lowest bed is a hard coarse sandstone which forms the quartzite ridge called the Stiper Stones, in Shropshire. Above this is a great thickness of ancient lavas and volcanic ashes, which form the Welsh mountain-ranges called Cader Idris, the Arenigs, and the Arans (see fig. 84). Fossils are numerous, and *graptolites* especially occur in great numbers.

Next comes the *Llandeilo Series* (well exposed near the Welsh town of that name), consisting of black shales and calcareous sandstones, containing numerous trilobites (as *Asaphus tyrannus*, fig. 103) and other fossils.

The succeeding and uppermost member of the Ordovician Formation is styled the *Caradoc and Bala Group*, because it is well seen near the hill of Caer Caradoc in Shropshire, and also round Bala Lake in Mid Wales. It contains thick shelly grits and slates, with two beds of limestone, and includes great local outpourings of lava and volcanic tuff, of which Snowdon, Moel Siabod, Penmaenmawr, and many other mountains in North Wales are chiefly or altogether formed.

Of fossils, such brachiopod shells as *Orthis alternata* and *Strophomena expansa* abound, with graptolites, trilobites, and many others—altogether nearly 700 species.

Ordovician strata are grandly developed in the Lake District,

where they form the *Skiddaw Slates*, the *Volcanic Series of Borrowdale*, and the *Coniston Limestone*. The Isle of Man consists of an extension of the Skiddaw Slates.

Strata of the same age occur in the south of Scotland (at Carrick, Moffat, Girvan, &c.). In the Ordovician cherts of this district Dr. G. J. Hinde has lately discovered many forms of radiolaria; these are microscopic siliceous organisms, and they closely resemble those living in the sea at the present day. Small patches of Ordovician rocks are known in the north-east and the south-east of Ireland. In County Waterford, Ireland, impure limestones of Bala age occur, containing the trilobites *Trinucleus hibernicus*, *Cybele tramorensis*, &c.

Economic Products.—In the Ordovician strata of the Lake District, much plumbago has been obtained from the Volcanic Series in Borrowdale; and roofing-slates are worked in the same district. Veins of lead are worked in the Arenig Beds of North Wales and Shropshire, and in the south (Leadhills) of Scotland.

Summary of the Ordovician Period.—After the deposition of the Tremadoc Slates a further sinking of the sea-bottom took place, so that in certain directions the Ordovician *overlap* the Cambrian strata.

The new (Ordovician) period thus commenced was characterized by volcanic outbursts on a scale of great intensity, during which volcanic islands were probably formed in North Wales and in the Lake District. The lavas and ashes then ejected now constitute some of the finest scenery in the British Isles.

Of the true aqueous rocks of this time, the sandstones indicate deposit near a shore, and contain many species of brachiopods and trilobites. The slates and shales were deposited in deep water, and include many and very peculiar *graptolites*, which in the Arenig rocks appear in great numbers. In the succeeding and higher members of the Ordovician Formation different species of these graptolites appear and disappear in turn, each species being found in one zone only. Thus the graptolites are exceedingly valuable as *type-fossils*.

CHAPTER XXIII.

THE SILURIAN FORMATION PROPER (UPPER SILURIAN OF MURCHISON AND THE GEOLOGICAL SURVEY).

Break or Interval between Ordovician and Silurian Strata.—The Silurian rocks were first studied in detail by Murchison in Shropshire and Herefordshire between 1831 and 1840.

There is evidence to show that considerable disturbances and changes in the positions of land and sea took place at the close of the Ordovician Period. Further, of 614 species of fossils which have been found in the highest Ordovician or Caradoc Beds only 115 (about one-sixth) are also known in the lowest Silurian or Llandovery Rocks, the strata which come next above them.

At this point then—between the Caradoc and the Llandovery Beds—geologists draw a line of demarcation and say, "Here ends the Ordovician; and here begins the Silurian".

Passage-beds between the Ordovician and Silurian.—The *Llandovery Beds* (Lower and Upper) consist of grits, conglomerates, slates, and shales, altogether 2000 feet thick, and are well developed near the town of Llandovery in Caermarthenshire.

Fig. 104. — *Pentamerus oblongus*; a Silurian brachiopod.

By many geologists the *Lower Llandovery* strata are assigned to the Ordovician Formation; but the fact is they are true *beds of passage*, linking together the Ordovician and the Silurian Formations, and formed during the interval between the two. This is shown by the fossils, for of the 204 species known from Lower Llandovery Beds, 105 also occur in the Caradoc rocks below, and 104 pass to the Upper Llandovery strata above.

Succession of the Silurian Strata.—The *Upper Llandovery Beds* of Caermarthenshire or *May Hill Sandstone* of

Gloucestershire is a sandy conglomeratic deposit which rests unconformably on all the rocks below it. It includes a sandy limestone full of the shells of a curious brachiopod, *Pentamerus oblongus* (fig. 104).

Upon this May Hill rock lies a great thickness of gray shales—the *Wenlock Shales*—which pass up into the *Wenlock Limestone*—a rock 300 feet thick and full of corals (*Halysites catenularius*—the "chain coral," &c.), with trilobites (*Phacops caudatus*), brachiopods, &c. It forms the bold ridge called Wenlock Edge in Shropshire, having resisted denudation better than the soft shales above and below it, which have been worn out into valleys. The same limestone has long been worked at Dudley, where it contains the fine trilobite called *Calymene Blumenbachii*, which is locally known as the "Dudley Locust".

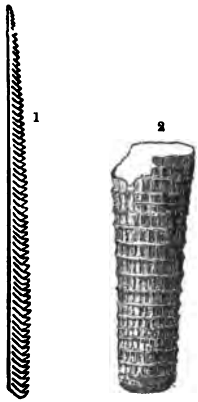


Fig. 105.—(1) *Graptolithus Ludensis*, a Ludlow graptolite; and (2) *Orthoceras annulatum*, a Silurian (Wenlock Limestone) cephalopod.

The third and uppermost division of the Silurian Formation is so well exposed round Ludlow in Shropshire as to have been named by Murchison the *Ludlow Series*. It consists of brown shales surmounted by a limestone band called the *Ludlow* or *Aymestry Limestone*, which is characterized by the brachiopod shell *Pentamerus Knightii*.

In shales just below the Aymestry Limestone at Leintwardine in Herefordshire, the first known traces in British rocks of VERTEBRATES occur, in the shape of a fish called *Scaphaspis Ludensis*. In Sweden, however, a fossil fish called *Cyathaspis* has lately been found in strata of the same age as our Wenlock Limestone.

The top of this Ludlow division is formed by red sandstones and gray shales—the *Downton Sandstones*,—which are true *passage beds* connecting the Silurians below with the Devonian Formation above. They contain a very remarkable 'bone-

bed', a layer only a few inches in thickness almost made up of the remains of fishes, crustaceans, &c. It is locally called 'gingerbread', and can be traced in Shropshire and the adjoining counties over an area exceeding one thousand square miles.

In the Upper Ludlow Rocks we meet with a few remains of *plants*, in the shape of leaves, stems, &c., belonging to the two genera *Actinophyllum* and *Chondrites.* (a sea-weed).

In Wales, Silurian strata extend from Llandovery in the south by Newtown, Welshpool, and the Berwyn Hills, into Denbighshire. But in Wales the limestones are absent, and all the Silurian beds are very sandy, grits and flagstones predominating; with the exception of graptolites there are but few fossils.

In Westmoreland and in the South of Scotland the Silurian strata resemble in character those of Wales. But further north, in the Pentland Hills, the beds are more like those of Shropshire, and at Lesmahagow in Lanarkshire we again find passage beds at the top, which here contain remains of the two genera of large crustaceans called *Pterygotus* and *Slimonia.*

In Ireland, Silurian strata (here hard sandy shales with black shales) extend across the island in a broad band from Coalpit Bay on the north-east to Galway, Mayo, and Kerry in the west and south-west.

Exposure of the Wenlock Beds near Dudley in Staffordshire.—Fig. 106 is from a photograph of the Wenlock Limestones and Shales at the Wren's Nest, a low hill near Dudley.

Near Dudley the Wenlock Limestone has been largely quarried, to be employed as a flux in the blast-furnaces of the adjoining coal-field. At the Wren's Nest it forms two bands of flaggy limestone, the upper being from 20 to 30 feet in thickness, and the lower from 35 to 40 feet; the two bands being separated by about ninety feet of shale. Both limestone bands are very fossiliferous, the brachiopod shell *Atrypa reticularis* occurring in them in thousands. The Wenlock Limestone is thought to have been a deep-sea forma-

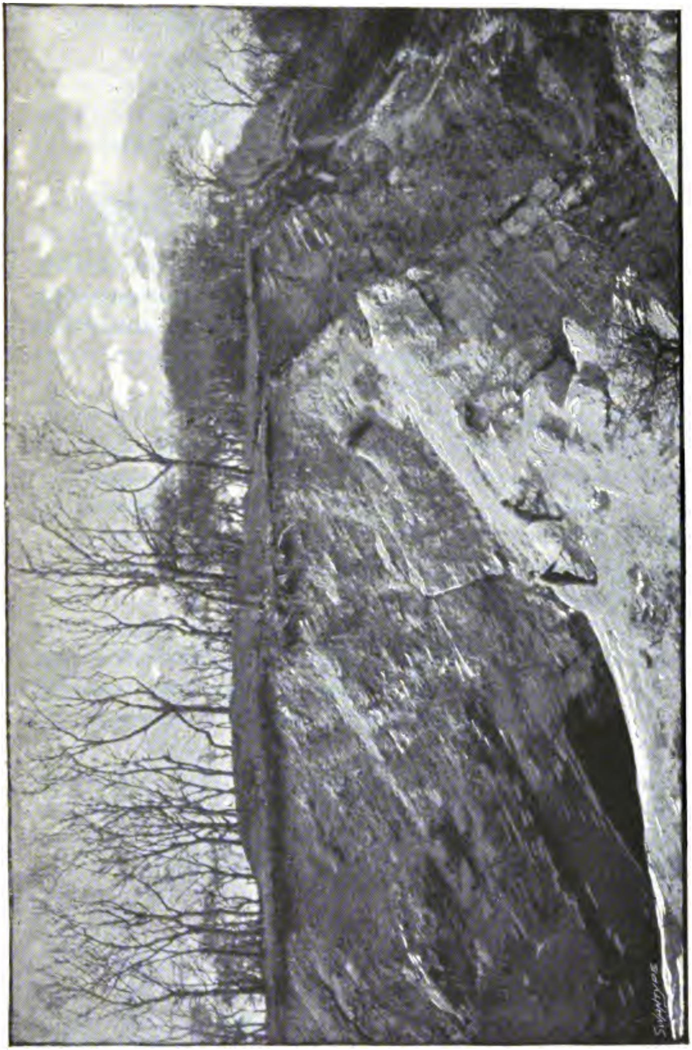


Fig. 106.—Silurian (Wenlock) Limestones and Shales at the Wren's Nest, near Dudley.

tion; and the presence of numerous species of simple corals seems to support this view. In the photograph the beds of rock (limestone below and shales above) are seen dipping towards the left hand (south-west) at an angle of about 45°. The limestone has been followed in underground workings, and the entrance to one of these (the so-called "caverns") is seen as a black hole at the base of the rocks.

Economic Products.—The limestone beds in the Silurian strata are burned in many localities to make *lime*. In South Staffordshire the Dudley or "Wenlock" limestone has been quarried on an immense scale to mix with the ironstone furnished by the adjacent *Coal Measures*. The limestone acts as a *flux*, enabling the iron ore to be melted by a lesser degree of heat than would otherwise be required.

Summary of the Silurian Formation.—In the west of England the five or six thousand feet in thickness of Silurian strata consist mainly of fossiliferous limestones and shales, which can be separated into three main divisions—(1) Llandovery, (2) Wenlock, and (3) Ludlow.

In the Lower Ludlow rocks the *last* graptolites and the *first* (British) fishes are found.

In North Wales and in the Lake District the Silurian strata are of much greater thickness than in the Shropshire district, sandy beds predominating in North Wales, and dark slates and grits in the Lake district; but fossils are scarce in these districts.

The highest beds of the Silurian formation (the *Downtown Sandstones*) contain numerous traces of land-plants (lycopods), and also some remarkable giant crustaceans. They pass conformably upwards into the Old Red Sandstone strata.

CHAPTER XXIV.

THE OLD RED SANDSTONE AND THE DEVONIAN FORMATION.

Origin of the Double Name of this Formation.— The geologists who lived during the early part of this century —William Smith and others—noticed that *beneath* the coal-bearing strata (Carboniferous Formation) there lay a considerable thickness of red sandy beds containing the remains of *fresh-water* fishes, shells, and plants; while *above* the coaly strata they found *another* or second thick mass of red sandstone.

To the lower and older red rocks they consequently gave the name of OLD RED SANDSTONE; while the higher and newer strata of somewhat similar appearance received the title of the NEW RED SANDSTONE.

The Old Red Sandstone Formation therefore lies between the Silurian rocks below and the Carboniferous rocks above.

But in Devonshire we find a considerable thickness of shales, slates, and limestones containing *marine* fossils; and these also lie *between* the Silurian and the Carboniferous Formations, and must therefore be of approximately the same geological age as the Old Red Sandstone mentioned above. The name "Devonian" has been given to those shales, slates, and limestones which were evidently being deposited in an open sea at or about the same time during which the Old Red Sandstone strata were being laid down on the floors of inland fresh-water lakes.

Areas in which the Old Red Sandstone occurs.— 1. In the west of England the "Old Red" stretches from Hereford and Monmouth into the neighbouring Welsh counties of Brecknock, Glamorgan, &c. In this region it is (where best developed) 10,000 feet thick; the lower part consisting of *red* and yellow sandstones, marls, and shales, with some beds of

concretionary limestone called 'cornstones'; while above these come similar *yellower* strata, with much brown and gray sandstone (the 'brownstones'). The prevailing red colour of the rocks is due to peroxide of iron; and wherever this is abundant, fossils are scarce. Still, remains of fishes and of crustaceans have been found.

2. Somewhat similar beds of the "Old Red" occur in the Cheviot Hills, where, however, they include igneous rocks 2000 feet in thickness (old lavas, tuffs, &c.), which form the highest points of the range.

3. Scotland is the classic ground of the Old Red Sandstone, for it was there that Hugh Miller, when a working mason at Cromarty, first collected its wonderful fossil fishes; and in his book entitled *The Old Red Sandstone*, we have a charming account of the rocks. The Scotch "Old Red" occurs in distinct basins of deposit, one of which runs across the country from Stonehaven and the Firth of Tay on the east coast to the Firth of Clyde on the west, and extends across St. George's Channel into the north of Ireland. The Pentland, Ochil, and Sidlaw Hills of the south of Scotland are composed of lavas and ashes 6000 feet in thickness, interstratified with "Old Red" sedimentary strata. These represent the outpourings of numerous volcanic vents, then in full activity.

4. A considerable tract of "Old Red" forms the Orkney Isles, and extends southwards by Thurso and Wick to the coasts of the Dornoch and Moray Firths.

5. A small patch lies at the foot of the south-west Highlands, among the hills of Lorne.

Sir A. Geikie has shown that all these five regions were probably old fresh-water lakes of great extent, in which sands and muds accumulated during this distant geological period; and he has accordingly named them (1) the Welsh Lake, (2) Lake Cheviot, (3) Lake Caledonia, (4) Lake Orcadie, and (5) Lake Lorne.

Fossils of the Old Red Sandstone.—Good examples of true land-plants are found, chiefly club-mosses and ferns; of the latter *Adiantites Hibernicus* is a beautiful example. These plants grew on the margins of the old lakes, and were swept

away by floods, &c. With these early fossil land-plants come a few insects.

Fishes of most remarkable forms are found, chiefly *ganoids*, as those covered with enamelled regularly-arranged bony scales are called. Of these we must name *Cephalaspis* (buckler-headed, see fig. 26), *Coccosteus* (berry-on-bone), *Pterichthys* (the wing-fish, fig. 107), *Holoptychius* (all-wrinkle), and *Osteolepis* (bone-scale). The living ganoid fishes are but few in number, and include the sturgeon, the bony-pike of North America, &c., all inhabiting rivers or lakes. The "Old Red" of the British Isles has so far yielded 120 species of fossil fishes, but most of these are very rare. The best localities for them are Dura Den in Fifeshire, Gamrie in Banffshire, and the paving-stone quarries of Arbroath; and at Whitbach (near Ludlow), Leominster, Kingston, and Cradley in Herefordshire.

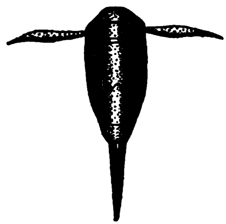


Fig. 107. — *Pterichthys Milleri*; an Old Red Sandstone (ganoid) fish.

All these "Old Red" fishes had unequally-lobed or *heterocercal* tails, the back-bone extending into the upper lobe of the tail.

In the same strata as these remarkable fishes there are found some large and peculiar crustaceans, such as *Eurypterus* and *Pterygotus anglicus*, the latter of which attained a length of six feet. These curious old crustaceans were something like our modern king-crabs.

In Ireland a fresh-water mussel—*Anodonta Jukesii*—occurs in the Old Red Sandstone of Kiltorcan. Many of the sandstones are ripple-marked.

The Devonian Series.—The rocks of North Devon—well exposed round Ilfracombe, Lynton, &c.—consist of gray slates, grits, conglomerates, and limestones, which dip to the south under newer rocks, and rise up to the surface again in South Devon, round Plymouth and Torquay, and extend thence westward to Padstow and the Land's End. In the south of Devon the limestones are crowded with corals (*Favosites polymorpha*,

&c.), brachiopods (*Stringocephalus Burtini*), and lamellibranchs (*Megalodon cucullatus*). *Calceola sandalina* (fig. 108) is a curious Devonian organism; it looks very much like a brachiopod shell, but naturalists believe that it really belongs to the corals. *Bronteus flabellifer* (see fig. 108) is a characteristic Devonian trilobite, with a fan-like tail. The limestones of South Devon are so hard and crystalline as to be called "madrepore marbles", and are polished and used for chimney-pieces, &c.

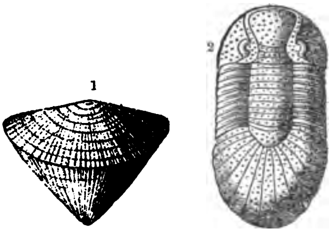


Fig. 108.—(1) *Calceola sandalina*, a Devonian coral; and (2) *Bronteus flabellifer*, a Devonian trilobite.

The gray shales near the top of the Devonian contain the trilobite *Phacops latifrons*, along with the coiled-up cephalopod shells called *Clymenia* and *Goniatites*.

Economic Products.—In Scotland the "Old Red" sandstones are largely quarried for building purposes near Dundee, Perth, and Roxburgh; while the thin-bedded sandstones of Arbroath and Caithness are employed for flagging. The intrusive igneous rocks—the "greenstones", "traps", &c.—are worked for road-metal, since they are extremely hard and tough. The well-known Scotch pebbles—agates, carnelians, &c.—are mostly found in the igneous rocks of this formation.

In Devonshire the hard coral limestones of Torquay yield slabs of "marble" which are employed for ornamental purposes; in other parts of the county—and also in Cornwall—veins of copper, iron, and lead are occasionally worked in the Devonian rocks (see fig. 47). Roofing-slates are also obtained in many quarries in the Devonian strata of these two counties.

Summary of the Old Red Sandstone or Devonian Formation.—At the close of the Silurian Period the central and northern parts of the British Isles were steadily and slowly elevated until they formed dry land. In this land four or five large lakes were formed, in which swam ganoid fishes and large crustaceans of strange forms, different species inhabiting the

different lakes. In or near the Scotch lakes active volcanoes erupted sheets of lava and showers of ashes, which we now find interbedded between the old lacustrine sands and muds. The waters of these lakes were charged with salts of iron, which colour the strata red, and whose presence was inimical to life; a fact which accounts for the comparative scarcity of fossils. Remains of such land-plants as lycopods and ferns occur, together with a few conifers, indicating a luxuriant flora.

South of the Bristol Channel a different state of things prevailed. There an open sea rolled, whose waters abounded with corals and brachiopods. The trilobites had now become few in number; but the cephalopods had largely increased in numbers, and in the *Goniatites* found in the Devonian rocks we have a genus of chambered shells which later on developed into the *Ammonites* of the Secondary strata. Altogether the Devonian slates, limestones, &c., of Devon and Cornwall have yielded about 450 species of marine fossils.

CHAPTER XXV.

The Carboniferous Formation.

Triple Division of the Carboniferous Strata.—At the close of the Old Red Sandstone epoch, the continent in which the "Old Red" lakes lay suffered depression. Most of the area now occupied by the British Isles went down far below the sea-level, and in the quiet waters of a deep sea a great thickness of limestone (the *Carboniferous or Mountain Limestone*) was gradually and slowly accumulated.

But as time went on this old sea-floor was slowly elevated, and in the shallower waters a great quantity of coarse sand (the *Millstone Grit*) was spread over the limestone.

Lastly, the Carboniferous sea became quite filled up, and its floor was raised up to or a little above the waters; and in great swamps, marshes, and low lands, vegetation grew so rich and rank as to produce the thick seams of coal which characterize

the third and uppermost member of the Carboniferous Formation—the *Coal-measures.*

Origin and Meaning of the Term "Carboniferous".—The word *Carboniferous* means literally "containing carbon". Carbon is the well-known black solid which we see as graphite (or black-lead) and which, when crystallized, forms the diamond. Now, not only does ordinary coal contain four-fifths of its weight of carbon, but the shales which lie between the coal-seams often contain so much carbon as to be quite black. Even the mountain limestone itself (composed chemically of carbonate of lime, $CaCO_3$) contains one-eighth of its weight of carbon. Therefore we see that the name *Carboniferous* is well chosen for a set of rocks[1] which are so rich in this element.

Succession of the Carboniferous Strata.—The various subdivisions of the Carboniferous strata are seen in orderly succession in South Wales and in Somersetshire.

1. First, resting conformably on the Old Red Sandstone, we find shaly beds—the *Lower Limestone Shales*—500 feet thick in the gorge of the Avon at Clifton, near Bristol, and containing marine fossils.

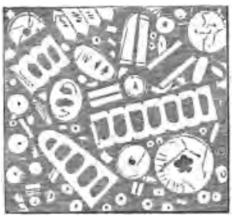


Fig. 109.—Section of Mountain Limestone Rock full of fragments of Encrinites.

Above this comes the true *Carboniferous Limestone*, 3000 feet in thickness, a massive rock often entirely composed of corals, shells, encrinites, &c. (see fig. 109). It is one of the best-known rocks in the world, forming the Mendip Hills (Cheddar Cliffs), and also occurring at Chepstow (along the Wye), and near Tenby, &c., in South Wales; and along the east side of the Vale of Clwyd, in North Wales.

In Derbyshire the *Mountain Limestone* (so named because it often forms or crowns hills) is grandly displayed round Matlock, Buxton, and Glossop. It is here a hard light-gray limestone containing many fossils, which are often only visible where the stone has been long exposed to the action of the

[1] It was first applied to them by Conybeare in 1822.

weather. Four of the most characteristic shells of the Carboniferous Limestone are shown in fig. 110.

In the North of England the Carboniferous Limestone extends from Clitheroe northwards by Richmond and Brough into Northumberland, where it forms the coast from Alnmouth to Berwick. In this region, however, it consists of several beds of limestone—the *Scar Limestone*, &c.—with beds of sandstone and shale between, indicating that the shore-line of the old sea

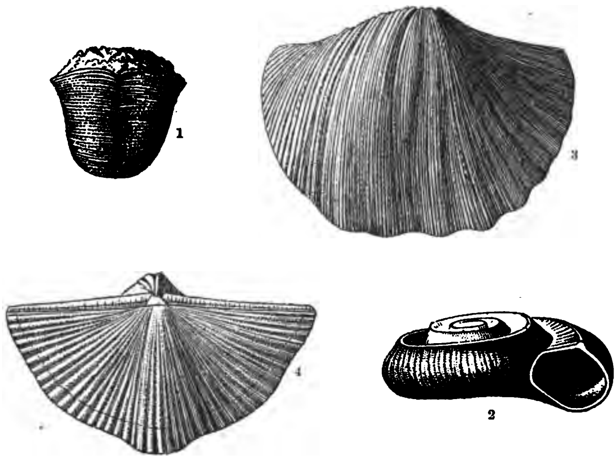


Fig. 110.—(1) *Bellerophon hiulcus*, and (2) *Euomphalus pentangulatus*, two gasteropod shells; (3) *Productus giganteus*, and (4) *Spirifer striatus*, two brachiopods.

lay in this direction; and this is confirmed by the fact that in Scotland the strata of this same Lower Carboniferous age (there 5000 feet in thickness) are sandstones and shales in which occasional seams of coal occur, and in which there are only a few thin beds of limestone. These northern beds are known as the *Calciferous Sandstone* of Scotland; and it must be remembered that although these Scottish rocks are so different in character, they were deposited at the same time as the Carboniferous Limestone of the centre of England and of South Wales.

In South Wales and Somerset the Carboniferous Limestone

passes upward into several hundred feet of shaly beds—the *Upper Limestone Shales.* In north-west Yorkshire similar shaly strata are called the *Yoredale Beds*; these are characterized by the cephalopod shell (see fig. 111) named *Goniatites sphericus.*

The *Culm-measures* ("culm" is a kind of stone-coal or anthracite) occupy the central part of a syncline or trough lying between the Devonian strata of North Devon and of South Devon. They consist of black shales, with gray sandstones and beds of chert and limestone. The seams of "culm" are irregular, and of no value as a source of fuel. The fossils include plants and shells which indicate that the culm-measures are on about the same geological horizon as the Calciferous Sandstone of Scotland, *i.e.* they are of Lower Carboniferous age.

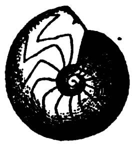


Fig. 111.—*Goniatites sphericus*, a Yoredale cephalopod.

2. **The Millstone Grit.**—In most places a considerable thickness of "grits" or coarse hard sandstones intervenes between the mass of limestone below (which we have just described) and the coal-measures above. Because of its applicability to grinding corn and similar purposes, this sandstone long ago received the name of the *Millstone Grit.* It is largely quarried for building purposes; and from the flaggy beds near Leeds comes the "Yorkshire stone", so much used for paving, &c.

Fossils are scarce—as is usually the case in coarse sandstones—but they include marine shells (the brachiopod *Productus semireticulatus*, &c.) with plant remains; the latter evidently drifted from neighbouring land.

In South Wales the Millstone Grit has long been called the *Farewell Rock,* because the miners know that when they reach it they bid good-bye to any chance of finding workable beds of coal. It varies in thickness from a few hundred feet in South Wales and Scotland, to as much as five thousand feet in the Pennine Chain.

3. **The Coal-measures.**—At the commencement of the period during which our valuable seams of coal were formed,

we must picture the British Isles as forming part of a large inland sea, similar to, but larger than the Baltic Sea of to-day. Rivers poured sediment into this sea until it was filled up, or nearly so, and then they cut channels across the silty mass, through which they pursued their devious ways. The state of the country was in fact comparable to the now-existing deltas of the Ganges, the Nile, or the Mississippi; or—to come nearer home—to that of the Rhine; which river, aided by

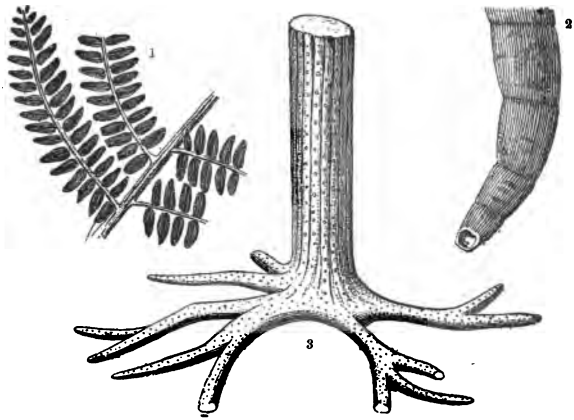


Fig. 112.—(1) *Neuropteris gigantea*, a fern; (2) *Calamites cannæformis*, a "horse-tail": and (3) *Sigillaria* (a lycopod), with its roots (known as *Stigmaria*) attached.

neighbouring streams and tributaries, has formed the greater part of Holland and Belgium.

But in the ancient coal-measure times the climate was extremely moist and warm. The plants were of quick-growing varieties, and they grew so rankly and luxuriantly, layer upon layer, plant upon plant (each as it died forming part of a mass of peaty soil in which other plants could grow), that all the land was soon covered with dense and matted forests (see figs. 112 and 113).

But at frequent intervals slight and gentle depressions of this old land occurred; and after each of these depressions the waters once more rolled over the old forests, bringing sand

and mud, by which each thick bed of vegetable matter was in turn covered up and pressed down. In this way the beds of shale and of sandstone which we now find *between* the seams of coal were formed. In this way, too, a new land surface was in time formed, on which new forests grew, to produce in their turn a second seam of coal; and so on.

"Underclay" found below Coal-seams.—It was first pointed out by Sir W. Logan in 1840, from his study of the South Wales coal-field, that almost every seam of coal is underlaid by a bed of gray clay (which miners call the "underclay") full of roots and rootlets. This underclay is in fact *the soil* in which the coal-forests grew. In some places stumps of trees have been found still standing on this underclay, and with their roots penetrating into it. It is very common to find the roots only, the tree-stumps having decayed and been broken down. To a certain kind of root which is of very common occurrence in the underclays the name of *Stigmaria* has been given. The existence of this underclay proves that the vegetable matter which forms coal in most cases *grew where we now find it.*

Coal-measure Plants.—In the British Carboniferous strata 328 species of fossil plants have been found. These nearly all belong to the lowly-organized simple flowerless plants which botanists call *cryptogams,* such as the ferns, club-mosses, and horse-tails. There were also some coniferous trees, allied to our pine-trees; and one or two examples of flowering plants have been found.

The ferns often occur in a perfect state of preservation, and of them we may mention the two genera known as *Pecopteris* and *Neuropteris* (fig. 112).

The living lycopods or club-mosses do not exceed the height of 3 feet; but in Carboniferous times these plants grew to the size of large trees. The *Lepidodendron* ("scale tree") is so named from the spirally arranged diamond-shaped scars on its stem, left by the leaves which had dropped off. Some trunks of this plant which have been found embedded in coal-measure shale exceed 50 feet in length. It bore a cone-shaped fruit, which has been called *Lepidostrobus.*

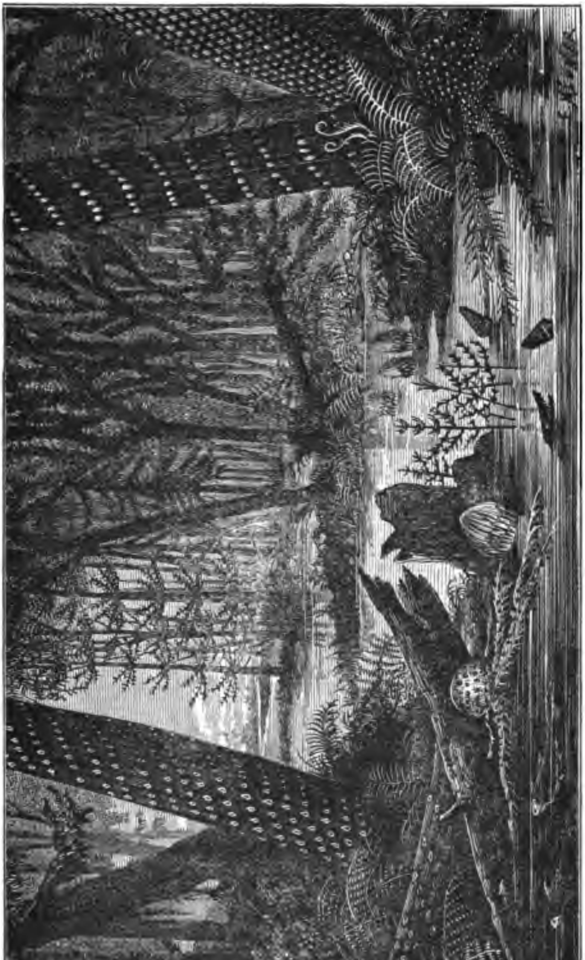


Fig. 113.—Restoration of a Coal-measure Forest, showing *Sigillaria*, *Lepidodendron*, Calamites, Ferns, &c. Fishes and Amphibia swim in the waters of the old swamp.

Another coal-measure plant which attained the dimensions of a tree was the *Sigillaria* (Lat. *sigillum*, a seal), whose bark bore leaf-scars arranged in vertical rows. The roots of *Sigillaria* were for a long time thought to be an independent plant, which was named *Stigmaria*; but the question was settled by finding certain stems or trunks with the roots still attached. In these examples the stem was certainly a *Sigillaria*, and the roots were as unmistakably the plant called *Stigmaria* (fig. 112).

Plants allied to our modern "horse-tails" also grew in abundance during the Carboniferous epoch; they are called *Calamites* (figs. 112 and 113).

Conversion of Vegetable Matter into Coal.—In the black shining stone we call coal the individual plants cannot be distinguished. They have been so crushed and mashed together, and withal have been so chemically altered by the action of a moist heat combined with pressure, that in outward appearance all trace of their vegetable origin is lost. But thin slices of coal still show, under the microscope, the fibres and spores of the plants from which the coal was formed.

The fact that coal has been formed from vegetable matter is also shown by the results of the chemical analysis of different kinds of coal as compared with wood, peat, &c. (see p. 109).

Animal Life of the Coal-measures.—The animals of the coal-measures are but few in number as compared with the abundant remains of plants—the *flora* is rich, the *fauna* poor. A freshwater bivalve shell, *Anthracosia*, is rather common; ganoid fishes, such as *Megalichthys*, still flourished; a little land-shell (*Pupa*) has been found in the coal-measures of Nova Scotia; and examples of spiders, with cockroaches and other insects, are also known. Of the Amphibia twenty-six species belonging to the genera *Archegosaurus*, *Pholiderpeton*, &c., have been found in the British Coal-measures.

How Elevation and Denudation separated our Coal-seams into distinct "Basins".—There can be little doubt but that the coal-forests grew, and coal-seams were formed, over the greater part of England, the south of Scot-

land, and most of Ireland. The mountains of North Wales and of the Scottish Highlands rose then, as now, high above the surrounding plains, and were probably bare.

But since the Carboniferous period the land now forming the British Isles has been elevated and depressed several times, and these movements have taken place very unequally. At the close of the Carboniferous epoch ridges of high land—such as the Mendip Hills—were formed running east and west, and from the tops of the anticlinals thus produced all the coal-measures were swept away by the forces of denudation. At or soon after the same period elevation also occurred along lines running north and south (the Pennine Chain, for example), and the denuding action was repeated. The final result was that the coal-seams, &c., once more or less continuous over all the country, were formed into detached areas or *basins.*

Coal-fields of the British Isles.—There are ten areas or "basins" in England and Wales, where coal-seams of great thickness, value, and extent occur. These are (1) Northumberland and Durham; (2) Whitehaven; (3) Yorkshire, Nottingham, and Derby; (4) Lancashire; (5) N. and S. Staffordshire; (6) Flintshire; (7) Shropshire; (8) Forest of Dean; (9) Bristol; (10) South Wales: in addition there are seventeen smaller and less important tracts. The total surface area of coal-bearing strata in England and Wales is about 4300 square miles. It will be seen that all these coal-fields lie west and north of a line drawn from the mouth of the Tees to Leicester and thence to Bristol. In the south and south-east of England no coal-seams crop out at the surface, and until 1890 no coal was known to exist beneath the surface in that part of the country; this absence of cheap fuel has greatly affected the habits and occupations of the people inhabiting the southern and south-eastern counties.

In Scotland there are five principal coal-tracts: (1) Lothian; (2) Fifeshire; (3) Clackmannan and the Clyde Basin; (4) Ayrshire; (5) Lesmahagow: their total area is about 1700 square miles, and they lie in Lanarkshire, Ayrshire, &c., between the Firths of Forth and of Clyde.

Ireland possesses small coal-fields in Tyrone and in Leinster, but they are of no practical importance.

The thickest seam of coal in the British Isles is the famous "Ten-yard Seam" of South Staffordshire, which is sometimes nearly 40 feet in thickness; but the average seams worked do not exceed 3 or 4 feet. There are five other workable seams of coal in South Staffordshire, each of which represents an old land surface. Between these six coal-seams come more than 1000 feet of sandstones and shales, representing the accumulations of sediment which the Upper Carboniferous sea heaped upon each old forest in turn as it sank beneath the waves.

Associated with the coal-seams in this and in most of the other British coal-fields are valuable beds of clay-ironstone.

The quantity of coal raised annually in Great Britain now amounts to not less than 190 millions of tons, and the amount is steadily increasing. One of the deepest coal-mines in Britain is the Ashton Moss Colliery, in Lancashire, the extreme depth of which is 3086 feet. By means of *boreholes* put down to depths of from 800 to 2000 feet many attempts have been made in recent years to ascertain the existence of concealed (because covered over by newer rocks) coal-basins in the south and east of England, and in 1890 coal-measures were reached in a boring at Dover at a depth of 1157 feet. This is a matter of great importance, as there is reason to believe that our present coal-fields will be practically exhausted in three or four centuries.

Economic Products.—The Carboniferous strata of the British Isles contain a wealth of mineral matter, which has been the main cause of our prosperity as a nation. The quantity of coal extracted annually from these rocks is truly enormous, and has increased at a surprising rate, as is shown by the following table:—

	Tons.		Tons.
1660	2,250,000	1876	134,000,000
1750	5,000,000	1888	160,000,000
1854	64,500,000	1892	185,500,000
1866	102,000,000	1894	188,277,000

The fact that thick beds of clay-ironstone and of limestone occur interbedded with and therefore in close proximity to the seams of coal, so that all three minerals may be, and often are, got out of one and the same mine, is a feature of great importance. The coal supplies the heat to melt the iron-ore, while the limestone (mixed with the iron-ore and coal) acts as a flux and enables this to be done at a moderate heat. This is the reason why iron can be produced more cheaply in Great Britain than in any other country. The brassy-looking streaks often seen in coal are composed of *iron pyrites*, a mineral which is a compound of iron and sulphur; it is also found in nodules and in cubical crystals.

The beds of underclay or *fire-clay*, which underlie many of the coal-seams, form a valuable material for making furnaces, crucibles or melting-pots, fire-bricks, &c., for it is a material which can endure great heat without melting.

The great mass of the *Mountain Limestone* which lies at the base of the Carboniferous Formation is very largely quarried to burn into lime. This same limestone contains numerous veins of lead-ore and zinc-ore; and in some localities—as Derbyshire—is so hard and crystalline that it is called *marble*, and is used as an ornamental building-stone.

Alum has been largely made from the Coal-measure shales, especially in the Lanarkshire Coal-field.

Capital *building-stone* and *flag-stones* are obtained from the Millstone Grit and from the sandstone beds of the Lower Coal-measures.

Summary of the Carboniferous Formation.—Lying between the "Old Red" Sandstone below and the "New Red" Sandstone above, we have in the British Isles a great series of limestones, sandstones, and shales (the latter with interstratified seams of coal) whose maximum thickness approaches 18,000 feet. To the rocks formed during this epoch of the earth's history the name of *Carboniferous* has been given, from the abundance in them of the elementary solid—Carbon.

The lowest division of the Carboniferous strata is in England a massive limestone, the result of the growth of coral reefs and

of the abundance of encrinites, molluscs, &c., in a warm and clear and tolerably deep sea.

The rocks of the highest division, on the other hand, contain clear evidence of the existence during their formation of peat-mosses, jungles, marshes, and forests; the land forming by turns a delta and an estuary. Occasional volcanic outbursts diversified the monotonous scene.

In the middle of the Carboniferous rocks—dividing the deep-sea limestone below from the land-forests above—is a thick mass of coarse sandstone, the Millstone Grit.

CHAPTER XXVI.

The Permian or Dyassic Formation.

The New Red Sandstone.—The early geologists readily distinguished a considerable thickness of red beds which lay *above* the coal from the much older strata of similar appearance which lay *beneath* it; and to the former rocks they gave the name of "New Red Sandstone".

But in 1841 Murchison and other geologists announced that their more careful and minute examination of this New Red Sandstone showed that the fossils of its lower were very distinct from those of its upper beds; that the former, in fact, had as a class Palæozoic affinities; while the latter belonged to Mesozoic types. The original New Red Sandstone was, therefore, divided into two distinct geological formations. To the lower and older part Murchison gave in 1841 the name of Permian (from *Perm* or *Permia*, an ancient kingdom in Russia, where red sandy rocks of this age form nearly all the surface), but in Germany it is more frequently called the Dyas (from Lat. *duo*, two), because in that country it is composed of *two* well-marked divisions—red sandstones below, and magnesian limestones above. Thus there are two types of this Permian formation: the Permian type proper—a mixed series of red sandstones, marls, shales, and limestones, with some thin beds

of coal, as found in Russia; and the Dyassic type—red sandstones below, and magnesian limestone above, as seen in Germany.

The term "New Red Sandstone" (or, more briefly, the "New Red") is now applied in England only to the *upper* strata of the original group of beds to which this name was applied before Murchison's researches into these rocks were published. The name "*New Red*" is, in fact, now synonymous with the name "*Trias*" (see Chap. xxvii.).

Land Movements at the Close of the Carboniferous Epoch.—After the deposition of the Coal-measures a general but unequal upheaval of the rocks took place. A continent was probably formed of which the British Isles became a part, and in that continent were at least two lakes or inland seas of considerable extent, in which the Permian and the Dyassic strata were deposited.

Strata of the Dyassic Type in Britain.—Dyassic strata form the eastern boundary of the York, Derby, and Nottingham coal-field, extending as a continuous long narrow strip from the coast at South Shields (Durham) to Nottingham. They dip gently to the east, passing under Triassic strata in that direction.

The lower beds here consist of red sandstones and marls of very variable thickness (20 to 200 feet), resting *unconformably* on the Coal-measures, and containing a few plants resembling those which formed the coal, and also true cone-bearing trees (*conifers*), and a species of yew (*Walchia*).

The upper and more important division of the Dyas in this district is the *Magnesian or Dolomitic Limestone*, whose thickness in Durham exceeds 500 feet. It is a yellowish, crystalline, and somewhat porous rock, composed of varying proportions of carbonate of lime and carbonate of magnesia. It is in part a chemically-formed rock, much of it having been precipitated from water overcharged with mineral matter. At its base thin bands of clayey limestone occur called the *Marl-slate*. The fauna of the Magnesian Limestone includes 203 species of shells, fishes, &c. Of the former we may name the brachiopod *Productus*

horridus, the lamellibranch *Schizodus Schlotheimi* (fig. 114), and the gasteropod *Turbo helicinus*; the fishes are mostly small ganoids, and all the species have heterocercal tails; *Platysomus striatus*, *Palæoniscus elegans*, and *P. comptus* (fig. 114) are characteristic forms. Most of the shell-fish have a dwarfed appear-

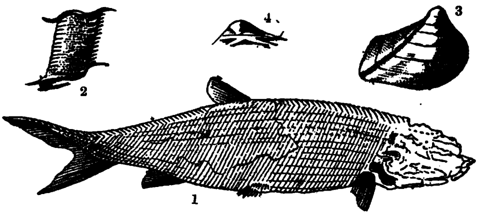


Fig. 114.—(1) *Palæoniscus comptus*, a Permian fish; one of its scales (2) is also shown, of the natural size. (3) *Schizodus Schlotheimi*, a bivalve shell; the hinge uniting the two valves is shown separately (4).

ance, and the whole fauna reminds us of that of some inland sea like the Caspian.

Strata of the Permian Type in the British Isles.—On the west of the Pennine Chain another lake was formed during Permian times, which extended from Warwickshire and the Malvern Hills on the south, to the Firth of Clyde on the north, while westward it sent a gulf into Ireland. Such a lake would be comparable in size to Lake Huron.

The deposits formed in this old lake we now find as red and variegated sandstones, as much as 3000 feet thick in Cumberland, where there is also at St. Bees a band of magnesian limestone 30 feet in thickness. Further south, in Lancashire, Staffordshire, &c., the Permian strata consist of red sandstones about 1000 feet in thicknesss which border and partly overlie the coal-fields.

In the Clent and Bromsgrove-Lickey Hills of Worcestershire, and at Enville, Malvern, and Abberley, the Permian strata end off towards the south in some remarkable beds of breccia 400 feet in thickness, which contain calcareous bands. These Midland breccias were derived from older rocks, upon and close to which they doubtless rest, although the old rocks them-

selves are now almost entirely covered over and concealed by the newer strata formed of their debris.

The Permian rocks of Ayrshire and Dumfries in the south of Scotland contain lava-flows and ash-beds, evidences of volcanic activity in that district during Permian times.

In Ireland there are some small and isolated patches of Permian rocks in Armagh and Tyrone.

The fossils in these western lacustrine deposits (Permian type) are fewer than those of the eastern lake (Dyassic type), but they are similar in character.

Economic Products.—The Magnesian Limestone is largely quarried for building-stone in Yorkshire, Nottinghamshire, and in Durham, and has furnished the material for many churches and cathedrals, and for the Houses of Parliament. It is also burnt into lime, and is used as a source of magnesia.

Summary of the Permian or Dyassic Formation.—At the end of the Carboniferous Period the British Isles were elevated to form part of a large tract of land. In this land were at least two salt lakes or inland seas of considerable extent, one lying on the east, and the other on the west of the Pennine Chain. In each of these lakes a considerable thickness of red sandstones, marls, and breccias was deposited; and in the eastern or Dyassic lake *dolomite* (magnesian limestone) was also deposited on the top of these red rocks. The Permian fauna and flora have a general likeness to the animals and plants of the *palæozoic* rocks; among plants the cycads and among animals the reptiles here make their first appearance.

COMPARISON OF THE THREE OLDER WITH THE THREE NEWER PALÆOZOIC FORMATIONS.

The Older or Lower Palæozoic rocks (including the Cambrian, Ordovician, and Silurian formations) are characterized by the remains of *marine* forms of life as fossils; for there are very few, if any, indications in them of terrestrial or fresh-

water deposits. But even in these Older Palæozoic formations there is clear evidence that the conditions of life were but little different from those of the present day. The climatic conditions were similar, as is shown by the rain-pittings, and by the trails and burrowings of marine organisms. All the great groups of the Invertebrata are represented in the older palæozoic strata, but the vertebrata are practically absent. Remains of Foraminifera and of Radiolaria occur; sponges with siliceous skeletons certainly existed; and the great group of the Hydrozoa is typified by various forms of graptolites. The Brachiopods are very abundant, the persistent species named *Lingula* being especially common. The true Mollusca are rare. The Arthropods nearly all belong to a now extinct group—the Trilobita—being introduced in Lower Cambrian times by the two genera known as *Olenellus*, and *Holmia.*

But in the Newer or Upper Palæozoic formations (Devonian and Old Red Sandstone; Carboniferous; and Permian) we get clear indications of an extensive terrestrial fauna and flora, the plant life especially being represented by many and varied forms.

The marine fauna of these Newer Palæozoic rocks has much in common with that of the Older or Lower Palæozoic deposits; but there are many striking differences. Thus, in the Upper Palæozoic strata we may notice the presence of ganoid fishes in great numbers and variety, including such genera as *Coccosteus*, *Pterichthys*, *Diplacanthus*, &c.

The Trilobites lived on in tolerable abundance in Devonian times; but they die out in the Permian system, being represented there by one genus only—*Phillipsia.* The Cephalopoda are represented in the Upper Palæozoic rocks by *Clymenia* and the *Goniatites*, coiled shells which are evidently the forerunners of the true Ammonites of the Mesozoic formations. The Brachiopods are still numerous; but the most notable increase among the Mollusca is in the Lamellibranchs and Gasteropods. The graptolites have entirely disappeared.

The terrestrial fauna and flora of the Newer Palæozoic times is the first and therefore the oldest known to us. Large

gymnosperms (the Cycads) put in an appearance; and cryptogamic plants are especially abundant both in numbers and variety. The ferns and club-mosses (Lycopods) attained their maximum development. Angiospermous plants were but poorly, if at all, represented. Fresh-water Lamellibranchs, closely resembling the modern fresh-water mussel (Unio) were very common. Many of the fishes appear to have been able to live in either salt or fresh water.

With the fishes appear the Amphibians, including the newt-like Labyrinthodon. Lastly, towards the end of the Newer Palæozoic period, and immediately before the dawn of the Cainozoic age, we find (in Permian strata) traces of the first true reptiles.

SECTION L.—THE MESOZOIC, OR SECONDARY SERIES.

CHAPTER XXVII.

THE TRIAS, OR TRIASSIC FORMATION: WITH THE RHÆTIC BEDS.

Restricted use of the name "New Red Sandstone".—The term "*New Red Sandstone*", as *now* employed by geologists, refers to the Trias only, and does *not* include the Permian strata which lie below.

Why we draw a Great Line of Division between the Permian and the Trias.—One of the great dividing lines of geology is placed *between* the Permian and the Triassic strata, separating them from one another. The Permian rocks are assigned to the Palæozoic system (of which they form the top); while the Trias is the first member of the Mesozoic system, of which it forms the base.

And yet, any one who had not studied geology would be likely to *class together* the Permian and the Trias; and, in fact, they were so classed by the early geologists, and one name was given to both, viz. the *New Red Sandstone.*

More careful and continued study has shown that the Trias is *unconformable* to the Permian; and, more important still, that the fossils of the Triassic *differ* very greatly from those of the Permian rocks. These two facts show that *a great interval of time* (unrepresented by any strata that have yet been discovered, in England at all events) really elapsed between the deposition of these two sets of rocks, which yet are so much alike in their general appearance.

Origin of the name "Trias".—The Trias (Lat. *tres*, three) was so named by Bronn, from the fact that in Germany (where he had studied it) it was composed of *three* distinct beds. The middle bed—a shelly limestone—is, however, wanting in Britain.

TRIASSIC SYSTEM.

Germany.	*England.*
Keuper.	Keuper.
Muschelkalk.	......
Bunter.	Bunter.

Areas occupied by Triassic Strata.—The red rocks of the Trias form extensive plains in Central England, stretching from the mouth of the Tees to the Bristol Channel, and forming most of Cheshire and much of South Lancashire. The vales of York, Eden, and the Clwyd are composed of Triassic red marls and sandstones; which also occupy a broad tract in the south-west between Taunton and Exeter.

In Scotland there is a patch of Keuper sandstone near Elgin; and another detached Triassic basin occurs in Antrim and Tyrone in the north-east of Ireland.

The Bunter Sandstone (New Red Sandstone).—*Bunter* is a German word which means 'variegated': it is applied to beds of soft red, yellow, and mottled sandstone, which attain a thickness in England of 2000 feet. In the lower part of this sandy mass is a thick bed of rounded quartzite pebbles—the well-known Bunter Conglomerate, or Pebble-bed, which can be traced from Worcester and Bridgnorth, by Cannock Chase, to Nottingham. The Bunter is practically unfos-

siliferous. Its porous strata yield, however, a splendid supply of pure water to many towns and villages situated on or near its outcrop.

The Keuper or New Red Marl.—The German name 'keuper' is probably a corruption of 'kupfer'—copper—and refers to the occurrence of copper-ore in strata of this age in Germany. The same mineral is found in the Lower Keuper Sandstone at Alderley Edge in Cheshire. The lowest part of the Keuper consists of a series of laminated micaceous sandstones, called the "waterstones", because they yield an abundant supply of water when pierced in well-sinkings, &c. Above these we find a mass of red, gray, green, and variegated marls, as much as 3000 feet in thickness in Cheshire, but thinning in a south-easterly direction to 700 feet in Warwickshire and Leicestershire. The New Red Marls contain near the top a thin irregular band of sandstone (the Upper Keuper Sandstone), in which, and also in the waterstones below, the bones, teeth, and footprints of a large amphibian have been found—the *Labyrinthodon*, so named from the complex labyrinth-like structure of its teeth (fig. 115). Rain-pittings and ripple-marks are common in the Keuper Sandstones, together with the remains of a tiny crustacean, *Estheria minuta*; and two or three genera of marine bivalve shells have been found in the same beds in Warwickshire.

Fig. 115.—Footprints and Tooth of *Labyrinthodon*.

The Hemlock Stone at Stapleford Hill, near Nottingham, of which fig. 116 is a photograph, is probably composed entirely of Keuper Sandstone. The individual particles of sand composing this 'monument' have been shown by Prof. F. Clowes to be cemented together by barium sulphate, which is practically insoluble in water. It is to this cementing material that the Hemlock Stone owes its present position and shape. Rain, frost, wind, and driving sand, are the principal artists which have sculptured out the Hemlock-stone; carving away the

softer and more easily acted upon material which formerly surrounded it, and thus leaving a relic of sub-aerial denudation

Fig. 116.—The Hemlock Stone, near Nottingham.

in the form of a pillar of sandstone which now rises to a height of about 40 feet.

Occurrence of Rock-salt and of Gypsum in the Keuper.—The beds of rock-salt in the Upper Trias are the chief source of that useful mineral, common salt. It is mined at Northwich in Cheshire; and it is also pumped up in the form of brine (from which white table-salt is then obtained by evaporation) at several places in Cheshire, and at Droitwich and Stoke Prior in Worcestershire. It occurs interstratified with

the Keuper Red Marls in two or more beds, each from 75 to 120 feet in thickness. But all through the Keuper Marls we come upon evidence of the existence of salt during the time of the deposition of these beds, in the form of little hard cubes of marl (from one-eighth to one-quarter of an inch in diameter), which are pseudomorphs of rock-salt; that is, they were once crystals of salt, but the salt has been dissolved by water percolating through the rock, and has been replaced, particle for particle, by the marl carried by the water. Either as solid rock-salt (which is often tinged red by the presence of a little oxide of iron), or as brine, about 3,000,000 tons per annum of salt are now obtained from the Upper Trias of England.

Rock-salt has also been found in Triassic strata at Middlesborough in Durham, at a depth of more than 1000 feet.

The Keuper Marls also contain large quantities of *gypsum*, a rather soft white mineral, which is composed of sulphate of lime. When compact it is called *alabaster*; and when crystallized it is known as *selenite*. When burnt and ground to powder this gypsum is sold under the name of *plaster of Paris*, a substance which is much used for making casts, and as a cement. Gypsum is or has been largely worked at Chellaston and Aston in Derbyshire, Tutbury in Staffordshire, and Newark in Nottinghamshire.

How the Triassic Strata were Deposited.—During the Triassic Period conditions generally similar to those of Permian and Old Red Sandstone times prevailed. The British Isles formed part of a continent or large tract of land, in which lay an inland or land-locked sea or lake of considerable extent.

Rivers ran into this sea, carrying in solution various minerals dissolved out of the rocks, more especially salt, gypsum, and various compounds of iron. The sun shone fiercely on the old lake, and for long centuries evaporated daily much pure water from it; the consequence being that the water left behind grew more and more impure, until at last it contained more mineral matter than it could hold in solution.

Each grain of sand and of mud that the rivers swept into the lake was then covered by a coating of red oxide of iron before

it sank to the bottom. And towards the latter part of this period (while the Keuper Marls were being formed) much salt and gypsum were also deposited in like manner on the floor of the old Triassic salt-lake.

At the present day we see a somewhat similar state of things in the Dead Sea of Palestine, and in the Great Salt Lake of Utah in North America.

Economic Products.—The Trias is the great source of our supply of *salt.* The salt mines and brine springs of Cheshire, Worcestershire, and Durham have already been mentioned.

The soft red sandstone beds of the Bunter and Lower Keuper yield *moulding-sand*, which is much valued for metal-casting. The harder beds are used as building-stone, but as a rule they do not stand the weather well.

Summary of the Triassic Formation.—Under the name of the *Trias* we include in England strata which vary in thickness from a few hundred to 4000 feet, and which are sandy in the lower part, clayey in the upper. It is in Cheshire and South Lancashire that the Trias attains its maximum thickness.

In Germany the name *Trias* is correct, for the beds there are plainly divisible into *three* parts—Bunter, Muschelkalk, and Keuper; but the middle division—the Muschelkalk, a gray shelly marine limestone—does not occur in England.

The English Trias was deposited throughout, in and around a shallow inland sea or lake, whose waters were frequently charged to excess with common salt, with gypsum, and with oxide of iron. In sueh waters little life could exist; and fossils are accordingly extremely rare in the Bunter and Keuper strata. The Muschelkalk marks a period when the open sea, bringing with it an abundance of marine life, was admitted for a time to the German lake; but no such episode occurred in Britain, where the deposit of red sand and mud was more or less continuous.

THE RHÆTIC OR PENARTH BEDS.

Beds of Passage.—We have seen that the Triassic strata were probably deposited, altogether or in part, in extensive salt lakes or inland seas. At the close of the Triassic period, the waters of the ocean were admitted to these areas by the sinking of the land at some point or other of their margins. With the sea-water came many living things—fishes, shells, &c.—and the very scanty life of the Triassic lake was replaced by an abundance of marine life.

But the change was a slow and a gradual one, and the strata now to be described—the Rhætic or Penarth Beds—mark the time of transition. They consequently form *passage-beds* between the Triassic marls and sandstones below, and the Liassic shales and limestones above, linking the two great formations together, and partaking somewhat of the characteristics of each.

The Rhætic Beds were until lately associated with the Lias, of which they were considered to form the base; but of late years some eminent geologists have urged that they should rather be placed at the top of the Trias. Others, again, would draw the line of demarcation at the top of the Rhætic Gray or 'Tea-green' Marls, placing these in the Trias; while the Rhætic Black Shales and White Lias they would class with the Lias proper. All this goes to show that the Rhætic beds are, as we have said, really transition strata or *beds of passage.*

Rhætic Strata Abroad.—In the old Roman province of *Rhætia*, which occupied an Alpine district between Bavaria and Lombardy, we find the typical Rhætic beds, in thickness not less than 3000 feet, consisting of limestones, dolomites, and shales containing abundant remains of life. Everywhere throughout Germany, Italy, France, Austria, &c.—wherever the true junction of the Trias with the Lias is exposed—we find beds of Rhætic age to occur. And the same is true even in the United States, and—as we shall see—throughout the British Isles.

The Penarth (Rhætic) Beds of the British Isles.—Mr. C. Moore, of Bath, was the first to recognize (about 1861) the existence of Rhætic Beds in England. They stretch across the country from Lyme Regis and Axmouth on the Devon coast to Redcar in Yorkshire, and are exposed at many points in Somerset (Beer Crocombe, Watchet, &c.); on the Bristol Channel (Penarth, Garden Cliff, Aust Cliff, &c.), and thence by Stratford-on-Avon and Leicester, northwards to Redcar. The same beds also occur near Elgin in Scotland, and Londonderry in the north of Ireland.

The finest British section is that at Penarth, a mile or two south of Cardiff; and for this reason Mr. H. W. Bristow proposed, in 1864, the name of **Penarth Beds** for the equivalents of the Rhætic strata in this country.

The section seen in the Penarth cliffs is as follows:—

LOWER LIAS LIMESTONES.

Rhætic or Penarth Beds.	White Lias Series, 18 feet.	Sandy shales, including beds of hard limestone. Fossil shells, such as *Modiola minima*.
	Black Shales, 24 feet.	Black shales, containing thin beds of shelly limestone (*Avicula contorta*, *Cardium Rhæticum*, &c.). Bone-bed full of fish remains.
	Tea-green Marls, 28 feet.	Greenish-gray, jointed, crumbling marls, containing layers of cream-coloured, white, and red marls, with a few fish-scales.

KEUPER RED MARLS.

The extreme thickness of the Rhætic Beds in England is 150 feet; but their *average* thickness is less than half this amount.

Rhætic Fossils.—The pretty little star-fish, *Ophiolepis Damesii*, occurs along with such molluscs as *Avicula contorta*, *Cardium Rhæticum*, *Modiola minima*, *Anoplophora musculoides*, &c. At the base of the black shales there is usually a bone-bed, consisting of teeth and scales of such fishes as *Hybodus minor* and *Gyrolepis Alberti*, imbedded in a hard sandy matrix.

Since the "twisted shell" *Avicula contorta* is so common in the *Rhætic strata* and is never found in any other formation,

the name Avicula Contorta Beds has been sometimes used to designate the Rhætic Formation.

The Oldest Known Mammal.—In the form of small teeth the Rhætic strata contain the earliest known traces of the highest division of the Animal Kingdom—the *Mammalia.* In 1847 Professor Plieninger found two very small teeth, each having a "well-defined enamelled tuberculate crown, supported by two distinct roots or fangs" (characters distinctive of mammalian teeth) in a Rhætic bone-bed near Stuttgart in Germany. To the animal from which these teeth were derived Plieninger gave the name of *Microlestes antiquus* (ancient little ravener).

In 1858 Mr. Charles Moore obtained a number of very similar teeth from fissures in the Mountain Limestone rock at Holwell, near Frome, in Somersetshire. This limestone must have formed part of the floor of the Rhætic sea, whose sediment filled up the fissures.

In a bed of Rhætic sandstone at Watchet, in Somersetshire, Professor Boyd Dawkins found a small two-fanged molar tooth (of a small mammal named *Microlestes Rhæticus*) in 1864.

These early mammals belonged to the lowest of all the mammalian tribes—the *Marsupials* or pouched animals, now so common in Australia. The little banded ant-eater of South America, which lives upon insects, and is about the size of a rat, is probably something like Microlestes in habits and in appearance.

CHAPTER XXVIII.

The Jurassic Formation (Lias and Oolites).

Origin of the term "Jurassic".—The Jura Mountains occupy the north-west of Switzerland, separating that country from France. They are composed of a thick series of clays, shales, and limestones, to which in 1829 the name Jurassic was given by the French geologist Brongniart.

Subdivisions of the Jurassic Rocks.—It was soon recognized that the lower Jurassic strata were very distinguishable in their chief characters from the upper part. To the lower rocks, which were very clayey and shaly in their nature, with occasional bands of limestone of no great thickness, the name of LIAS was applied; while the upper Jurassic beds, which contained much more limestone, and also occasional beds of sandstone, received the name of OOLITES.

"Sir A. C. Ramsay considers that the Jurassic strata of Britain were sediments laid down in warm seas surrounding an archipelago, of which Dartmoor, Wales, and Cumberland formed some of the islands. The finer sediments were, no doubt, brought down by rivers, whose former presence is indicated by estuarine beds; the calcareous sands and freestones have been formed in part from comminuted shells and corals; while evidences of coral-reefs occur at some horizons."[1]

TABLE OF THE JURASSIC STRATA.

Upper Oolite	Purbeck Beds.	
	Portland Beds.	
	Kimeridge Clay.	
Middle Oolite	Coral Rag.	
	Oxford Clay, with Kellaways Rock.	
Lower Oolite	Great Oolite	Cornbrash.
		Forest Marble.
		Bath Oolite.
		Stonesfield Slate.
		Fuller's Earth.
	Inferior Oolite	Lincolnshire Oolite.
		Collyweston Slate.
		Northampton Sands.
		Midford Sands.
Lias	Upper Lias.	
	Middle Lias or Marlstone.	
	Lower Lias.	

[1] H. B. Woodward: *Geology of England and Wales.*

THE LIAS.

Origin of the word "Lias".—The name Lias is derived from "layers"—pronounced broadly by the Somerset quarrymen as "lyers"—a very suitable name for the lower beds of the Lias especially, since the alternation of thin beds of limestone and of shale gives to the rock a banded or ribbon-like appearance, which may well cause the workmen to describe it as occurring in "lyers".

Position of the Liassic Strata.—From Lyme Regis in Dorsetshire the Liassic strata are easy to trace through Somerset and East Gloucester to Warwick and Rugby, and thence through East Leicestershire and the East Riding of Yorkshire to the coast between Redcar and Whitby. Outlying patches of Lias occur at Needwood Forest (Staffordshire), Whitchurch (Shropshire), and near Carlisle, proving a former great westerly extension of these rocks; other outlying traces of which are, indeed, found in the north of Scotland, in the Hebrides, and in the north-east of Ireland.

Subdivisions of the Lias.—The word "Lias" was introduced into geology by William Smith about the close of the eighteenth century; and its subdivision into *Lower*, *Middle*, and *Upper Lias* we owe to his nephew, John Phillips, in 1829.

The Lower Lias has at its base many thin bands of argillaceous limestone separated by beds of shale. This "blue lias" is largely worked at Barrow-on-Soar (Leicestershire), and at Rugby and several other places, because it yields a valuable cement. Above these thin limestones we have a considerable thickness of clay, containing occasional nodular bands of limestone. These Lower Lias Clays form the fine grass country of East Leicestershire. The thickness of the Lower Lias varies from 450 feet in Dorsetshire to 800 feet in Leicestershire and Yorkshire.

Fig. 117 is from a photograph of a small quarry in the Lower Lias near Binton, in Warwickshire. The beds shown are right at the base of the Lias, and the Rhætic Beds are only a few

Fig. 117.—Quarry in Lower Lias Limestones and Shales, Binton, Warwickshire.

feet lower down. We see several thin bands of limestone at the base of the quarry, interstratified with thin beds of shale; while a thicker bed of shale occupies the upper portion of the exposed 'face' of the rocks. As far as this section or exposure goes, we can detect no 'dip' in the strata, which appear to be quite horizontal; but when we trace them over the adjoining fields we find that they incline slightly to the east. Fossils are not plentiful, but examples of *Ammonites planorbis* may be found by the diligent worker.

Fossils of the Lower Lias.—The Liassic rocks teem with evidences of life. The shells called *Ammonites*, which look

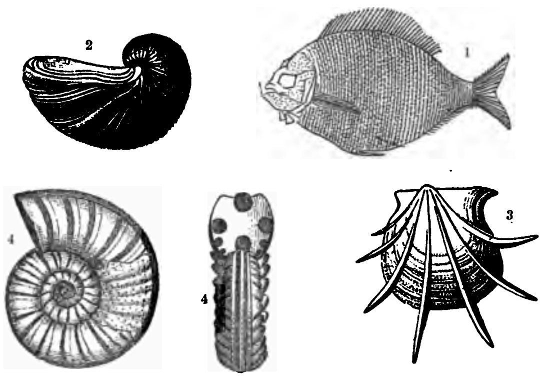


Fig. 118.—Liassic Fossils. (1) *Dapedius politus*; (2) *Gryphæa incurva*, a thick-shelled oyster; (3) *Avicula cygnipes*, a lamellibranch shell; (4) *Ammonites obtusus* (side and back view).

like little coiled-up headless snakes, here make their first appearance in British rocks[1], the earliest species being *Ammonites planorbis* in the "Blue Lias"; in higher beds come *A. angulatus*, *A. Bucklandi*, *A. obtusus* (fig. 118), and *A. oxynotus*. These are accompanied by such bivalve shells as *Ostrea liassica*, *Lima gigantea*, and *Gryphæa incurva* (see fig. 118), and by several large and remarkable reptiles whose bones have been found in large numbers at Lyme Regis and at Barrow-on-Soar. Of these reptiles the *Ichthyosaurus* was something like a crocodile;

[1] Abroad, true ammonites occur in both Triassic and Permian strata.

while the *Plesiosaurus* more nearly resembled a great lizard (see fig. 119). These creatures varied from 4 to 40 feet in length. They appear to have inhabited the waters of shallow seas, and to have preyed upon fish &c. The *Pterodactyl* was a flying reptile (see fig. 120).

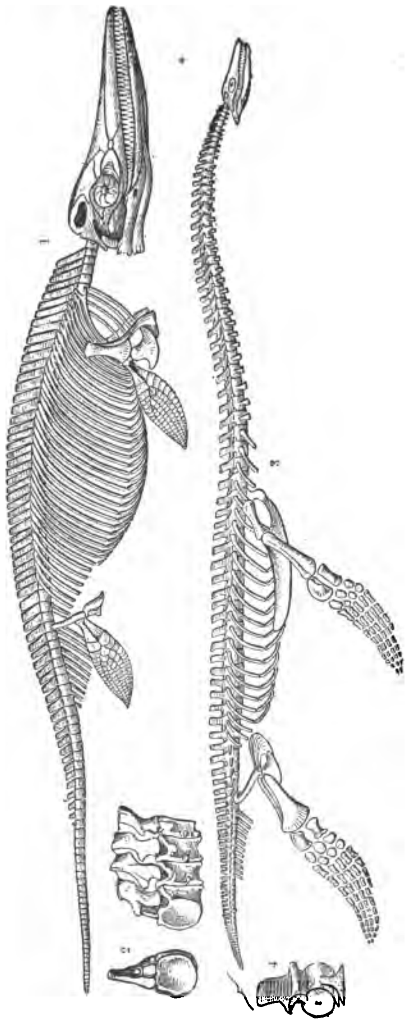


Fig. 119.—Liassic Reptilia. (1) *Ichthyosaurus communis* (with side and end view of costal vertebræ, (2)); (3) *Plesiosaurus dolichodeirus* (with view of cervical (neck) vertebra, (4)).

The Middle Lias is sometimes called the *Marl-stone*, because its upper part consists of tough clayey limestones containing much iron, which weathers at the surface to red or brown, while deeper down it is of a bluish tint. This hard Marl-stone "Rock-bed" is usually about 12 feet in thickness. It is only 3 feet thick in the cliffs on the Dorset coast between Charmouth and Bridport Harbour, but as we follow it northwards it thickens to 20 feet in the

Cotteswold Hills. In East Leicestershire the Marlstone is 30 feet in thickness, and forms a well-marked ridge, having resisted denudation better than the softer clays which lie above and below it. Finally it extends through East Yorkshire and runs out to sea in the cliffs at Staithes, north of Whitby.

This Rock-bed is or has been largely worked for iron at Cleveland in Yorkshire, and at several points in Lincolnshire (Denton, Woolsthorpe, and Claythorpe), Leicestershire (Holwell, Tilton, &c.), and Oxfordshire (near Blenheim, &c.).

The Marlstone is distinguished by the abundance of the two brachiopod shells *Rhynchonella tetrahedra* and *Terebratula punctata*, which in some places form nearly the whole of the rock, giving blocks of it quite an ornamental appearance; it has also a characteristic ammonite—*A. spinatus.*

The Middle Lias includes a considerable thickness of clayey beds below the Rock-bed. These Middle Lias clays can only be divided from the clays and shales of the Lower Lias by a study of their fossils. It is therefore very difficult, indeed often impossible, to draw upon a geological map the exact line of demarcation between the Lower and the Middle Lias. The early geologists took for their guides in mapping, just the most easily-distinguishable beds of rock; and if we were to limit (as they did) the term "Middle Lias" to the Rock-bed alone, it would be easy to map this division across England. But later researches have shown that the clayey beds below the Rock-bed are *connected by their fossils* with the Rock-bed, and hence must be classed and mapped with it. It is, indeed, possible to distinguish three bands or 'zones' in the Middle Lias Clays, each characterized by a peculiar species of ammonite, viz. *Ammonites Jamesonii*, *A. capricornus*, and *A. margaritatus.* Owing, however, to the fact that the opportunities of examining these strata are rather scanty, the junction of the Lower and Middle Lias is usually indicated on a geological map by a *dotted line*, indicating that the precise boundary line is unknown.

The total thickness of the Middle Lias varies from 40 feet

in Northamptonshire to 350 feet in Dorsetshire. In Yorkshire the beds are more sandy, and they exceed 100 feet in thickness in the cliffs south of Whitby.

The Upper Lias.—The third and uppermost member of the Liassic formation consists of a thick mass of blue or gray shaly clay, with occasional bands and nodules of limestone. The thickness is very variable, being 70 ft. in Dorset, 10 ft. in Somerset, 380 ft. near Cheltenham, 10 ft. in Oxfordshire, 200 ft. in Rutland, and from 50 to 200 ft. in Yorkshire.

In Yorkshire the Upper Lias was formerly the chief source of alum, whence the beds at Whitby and Redcar were called the "alum shales"; but the trade has now almost decayed away, as alum can be made more cheaply from coal-shales.

Jet, too, has long been obtained from the Upper Lias at Whitby. It is worked into ornaments and polished; but the trade has suffered greatly from foreign competition, and nearly all the jet ornaments now made at Whitby are fashioned out of imported Spanish jet. Jet is fossilized coniferous wood; it is a resinous variety of lignite.

How Fossils Indicate the Geological Age of a Rock.—The rocks of the British Isles have so far yielded about 16,000 species of fossils. The greater part of these are *extinct species*—that is, there is no animal or plant living now which is exactly like any one of them. Now of these extinct species each had its range in time. Usually we meet with it first in a certain stratum; it is very abundant in that and perhaps in the succeeding stratum also; but above and below these strata we seldom or never find it.

Thus fossils are the *medals of creation*; for just as a medal or coin will tell us in what king's reign it was made, so does the finding of a characteristic fossil tell us the geological age of the rock in which it occurs.

Some fossils, however, are of but little use for this purpose. Lowly organized, their high vitality and power of adapting themselves to surrounding conditions enabled them to live on from epoch to epoch.

Ammonite Zones.—As an example, on the other hand,

of fossils of very limited range we may take the chambered shells (cephalopods) called *Ammonites.*

It was said of the late Dean Buckland that if he were blindfolded and then put down suddenly in any part of England, he could, by simply examining the nearest rocks, tell upon what geological formation he was standing, and—approximately—where he was. Well, if the rocks contained ammonites, it is certain that any expert palæontologist could at all events prove the truth of the first part of this story.

The ammonites belong to the *Cephalopoda* ("head-footed" animals—so called because they move by means of tentacles arranged round the head), which constitute the highest class of the Mollusca or shell-fish. Of such cephalopod shells there are now living the *Argonaut* (paper nautilus), the *Pearly Nautilus,* the famous *Octopus*—so named from its *eight* tentacles, the *Sepia*—whose internal shell is the 'cuttle-bone' so often picked up on our shores, and a few others. The oldest cephalopod is the *Orthoceras,* which—appearing first in Cambrian strata—endured from very early times down to the Trias of the Alps. The Nautilus of our present tropical seas is another very long-lived genus, for it has been found as low down at least as the Ordovician Formation.

The Lias can be divided into eleven distinct zones, each of about 50 to 150 feet in thickness, by means of the following eleven species of ammonites:—

Upper Lias.......	Zone of *Ammonites jurensis.*
	" " *communis.*
	" " *serpentinus.*
Middle Lias......	Zone of *Ammonites spinatus.*
	" " *margaritatus.*
	" " *capricornus.*
	" " *Jamesoni.*
Lower Lias.......	Zone of *Ammonites oxynotus.*
	" " *Bucklandi.*
	" " *angulatus.*
	" " *planorbis.*

It must not be thought that these eleven life-zones are separated from each other by any absolutely hard-and-fast

lines. A few scattered specimens of each ammonite may be found, perhaps, in the rocks of the zones immediately above and below its own; what is meant is that each species named is most abundant in, and is therefore characteristic of, a certain 'horizon' or position in the Liassic Formation. It is the same with every other fossil; but as each species usually ranges for some distance above and below its own special horizon, it is the *whole* of the fossils from any particular stratum that we must take into consideration when attempting to decide, from the evidence of its fossils alone, the exact position of any rock-bed in the geological series.

Economic Products.—The broad plains formed of Liassic clays constitute fine grazing land. They are mostly in pasture.

The Marlstone yields much iron ore, especially in Cleveland (Yorkshire) and in Leicestershire.

Jet and Alum were formerly obtained in large quantities from the Upper Lias shales at Whitby.

Summary of the Liassic and Rhætic Formations.—At the close of the Triassic Period the land in Western Europe suffered depression. The waters of the open ocean were admitted into, and mingled with the extremely salt waters of the Triassic lakes. This sudden change killed the few fish, &c., which had inhabited those lakes, and their remains were deposited thickly on the old floor of the lake, forming what we now call the Rhætic *bone-bed.*

Then as the land continued to sink, the sea-water was slowly but more and more completely admitted; during which time the Rhætic strata—black shales with thin bands of limestone, altogether not more than 150 feet thick in Britain—were deposited. The depression continuing, the sea ultimately flowed uninterruptedly over central and western England, bringing with it an abundance of marine life, and the Liassic strata were then deposited. The dark clays and shales of the Lias, 1000 feet in thickness, were probably derived from Coal-measure shales, which then formed part of the coasts surrounding the Liassic sea.

We may imagine that the change from the Trias to the Lias

was very like what would happen at the present day if the coast of Palestine were to be depressed, so that the waters of the Mediterranean were slowly admitted to the Dead Sea.

CHAPTER XXIX.

THE OOLITES, OR OOLITIC FORMATION

(Including the Purbeck Beds).

Why William Smith used the word "Oolite".—The Oolitic strata have a special interest for English geologists, for it was in them that William Smith, the West of England surveyor, first made out (about the year 1790) the *order of succession* of the strata, and by this was led to his great discovery that "strata could be identified by their organic remains", *i.e.* by their fossils. He noticed that some of the limestone beds of the strata we are about to describe consisted of small rounded grains, which made them resemble the roe of a fish—indeed they were called "roestone" by the workmen. Hence Smith—when seeking a name for this set of strata—bethought himself of the term "Oolite", which means "egg-stone" (Gr. *oon*, an egg, and *lithos*, a stone).—Where the grains are very large, the limestone is called "pea-grit" or *pisolite* (Lat. *pisum*, a pea). Some beds which contain numerous and irregularly-shaped fragments of shells, corals, &c., are called *rag-stones.*

Range of the Oolitic Strata.—The Oolites form the coast of Dorset south of Swanage and Kimeridge; they are finely displayed at Portland and round Weymouth; from East Somerset they stretch north-east through Gloucester, Oxford, Bucks, Huntingdon, Northampton, Rutland, and Lincoln, to the Humber; they also occupy a considerable area in the north-east of Yorkshire, where they form the cliffs from Filey to beyond Scarborough.

In Scotland there are a few *outliers* of Oolite on the west coast in Skye, &c.; but the most interesting remnant of these

rocks is that which occurs at Brora in Sutherlandshire, and which belongs to the Inferior Oolite. The Oolitic strata here contain a seam of good coal 3½ ft. thick, which has long been worked. The 'roof' or top of this coal is a mass of marine shells, showing that the land on which the Oolite plants grew, whose remains now form this bed of coal, must have been submerged beneath the sea.

Subdivisions of the Oolites.—The table given on p. 252 shows the Oolites as divided into three sections—Lower, Middle, and Upper; each of these being again subdivided into certain well-marked strata.

Fig 120.—*Pterodactylus crassirostris*, a flying reptile found in the Oolite.

A distinct feature of the Oolite is the alternation of beds of limestone and of clay; and the result of this is the corresponding alternation of hills and vales which one meets with in crossing a district composed of Oolitic rocks, as in travelling from Gloucester to London, for example. The harder limestones stand out as ridges or hills, while the softer clays have been hollowed out by the agents of denudation into plains or valleys. The different bands of limestone and clay are not, however, continuous right across England, from Dorset to Yorkshire. Moreover, they vary greatly in their thickness, sometimes disappearing altogether, or being replaced by strata of a different nature. Thus the thick limestone beds which characterize the Lower Oolite in the Cotteswold Hills change into sandy beds of ironstone in Northamptonshire and Oxfordshire, only a few miles to the north-east. The Coral Rag, again, is only found at one point, Upware, near Cambridge, in the

long stretch of country which intervenes between Oxford and the East Riding of Yorkshire. This is no more than we should expect when we remember that the Oolites were deposited in a shallow sea, probably containing shoals and islands, and having an indented coast-line; a sea into which large rivers entered, in the estuaries of which some of the Oolitic strata were deposited.

Passage-beds from Lias to Oolite: the Midford Sands.—Round the little village of Midford, near Bath, some sandy beds—hence called the *Midford Sands*—are seen between the Upper Lias clays below and the Lower Oolite limestones above. On the Dorset coast, east of Bridport, the same sands are seen in the cliffs to be 200 feet thick. Their fossils include *Ammonites jurensis* and other liassic forms, and also several Oolite species. Hence the Midford Sands must be considered as passage-beds, marking a transition from the Lias to the Oolite.

The Inferior Oolite.—This is a limestone much used for building because it is a 'freestone', that is, it can be cut or carved equally well in any direction. On the west face of the Cotteswold Hills this bed is 264 feet thick, and it is largely quarried there at Leckhampton, just outside Cheltenham. Traced in a north-easterly direction we find this Inferior Oolite bed thinning to a thickness of only 10 feet at Woodstock. The term "inferior", as applied to this division of the Oolite, simply means the *lower* or bottom bed of the formation.

In the Midlands the Inferior Oolite consists of the *Northampton Sand* below (60 feet thick, largely worked for iron ore), and the *Lincolnshire Oolite Limestone* above; the latter forming the ridge called the "Cliffe", which extends from Ketton and Ancaster in Rutland (where this limestone yields a splendid building-stone) due north by Lincoln city to the Humber.

The characteristic fossils of the Inferior Oolite are *Ammonites Parkinsoni*, *A. Humphriesianus* (two cephalopods), *Pterocera Bentleyi* (a gasteropod), and *Terebratula fimbria* (a brachiopod).

The *Fuller's Earth* is a thick bed of greasy clay which in the West of England comes between the Great Oolite (above) and

the Inferior Oolite (below). It contains large numbers of a small oyster—*Ostrea acuminata.* The yellow fuller's earth is much used for cleansing and scouring cloth, since it has the property of combining with and so removing the greasy or oily matters that are naturally contained in wool.

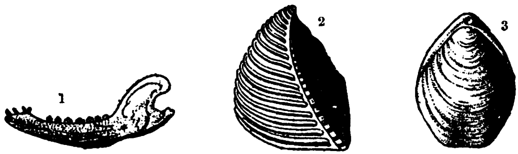


Fig. 121.—(1) *Phascolotherium Bucklandi* (lower jaw); (2) *Trigonia costata*, a lamellibranch from the Cornbrash; (3) *Terebratula perovalis*, a brachiopod from the Fuller's Earth.

The Great or Bath Oolite is about 120 feet thick in the hills round the town of Bath, where it is largely quarried for building-stone, as also at Corsham, Box, and Minchinhampton in the same district. At Stonesfield, in Oxfordshire, the Great Oolite has at its base some thin fissile beds which (because they are locally used for roofing purposes) are called the *Stonesfield Slate.* In this latter stratum the lower jaws of four small species of mammals have been found (*Amphilestes*, *Phascolotherium* (see fig. 121), *Amphitherium*, and *Stereognathus*). Two of these appear to have been insect-eating marsupials, somewhat resembling the Rhætic mammal *Microlestes.*

Fig. 122.—(1) *Megalosaurus*, a gigantic Oolitic reptile. (2) Tooth. (3) Jaw.

The Forest Marble (so named from its occurrence in Wychwood Forest, Oxfordshire) contains a hard shelly oolitic limestone, which has been polished to make mantel-pieces, &c., and hence is locally called 'marble'.

The Cornbrash may be considered as the top stratum of the Great Oolite. It is a coarse shelly irony limestone, which does not average more than 12 feet in thickness, yet which

can be traced right across England from Weymouth to Scarborough. Its characteristic fossils are a large oyster called *Ostrea Marshii*, and the pretty lamellibranch shell *Trigonia costata* (see fig. 121).

The Middle or Oxford Oolites have for their base a thin irregular stratum of limy sandstone called the *Kellaways Rock*, from a village of that name in Wiltshire.

Above this comes the *Oxford Clay*, a stiff bluish clayey mass, 600 feet thick, which forms a broad low-lying tract of country (mostly pasture-land) between Dorset, Oxford, and Lincoln. Its fossils include the beautiful *Ammonites Jason*, *Belemnites hastatus*, and a broad oyster-like shell—*Gryphæa dilatata*.

The Coral Rag and Grit is a rubbly limestone which was formed as a coral reef in the old Oolitic sea. From its superior hardness it usually forms elevated ground between the two plains or 'vales' composed of the Oxford and the Kimeridge Clays respectively. In the centre of England the Corallian strata are absent; but in the north-east of Yorkshire in the one direction, and from Oxford to Weymouth in the other, they average about 300 feet in thickness. Besides many species of corals, the Corallian beds contain such sea-urchins as *Cidaris florigemma*; and also the cephalopod shell *Ammonites perarmatus*, &c.

The Upper Oolites, like the Middle, consist of thick clays below, capped by limestones. The former (or clayey strata) are called the *Kimeridge Clay*, from the village of that name on the Dorset coast. They are black shales and marls 600 feet thick, in which crystals of selenite, and septaria (hard nodules of marl traversed by cracks which have become filled up with carbonate of lime), are not uncommon. Near Kimeridge the shales contain so much black bituminous matter that they have occasionally been used by the villagers as fuel.

The fossils of the Kimeridge Clay include *Ammonites biplex*, *Ostrea deltoidea*, &c.

The Portland Beds form the so-called 'Isle' (really a peninsula) of Portland, in Dorset; where there are extensive quarries in the oolitic limestones, which with some beds of

marl and sand (altogether 170 feet thick) constitute this member of the Upper Oolites. Portland stone has been used for many public buildings, including St. Paul's Cathedral. Inland, the same limestone is worked for building-stone at Swindon, and near Aylesbury. The fossils include the gasteropod shell *Cerithium Portlandicum*—called from its appearance the Portland 'screw'.

The Purbeck Beds form another peninsula (or 'isle') in Dorsetshire. At Swanage on the same coast they are 350 feet thick; but followed to the north-east they gradually become

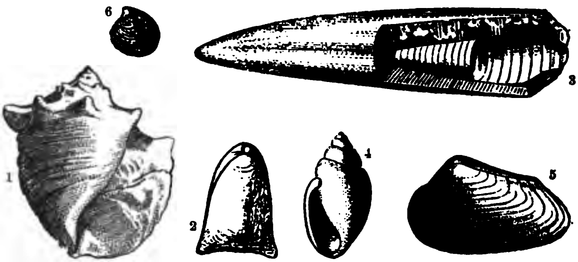


Fig. 123.—(1) *Purpuroidea Morrisii* (gasteropod): Great Oolite. (2) *Terebratula digona* (brachiopod): Bradford Clay. (3) *Belemnites abbreviatus* (cephalopod); Coral Rag. (4) *Physa Bristovii* (gasteropod): Purbecks. (5) *Unio compressus* (lamellibranch): Purbecks. (6) *Cyclas parva* (lamellibranch): Purbecks.

thinner, and cannot be traced beyond Brill in Buckinghamshire. They consist of marls, fresh-water limestones, and clays.

In the Dorset cliffs several 'dirt-beds' can be traced in the Purbeck strata. These are layers of soil, old land surfaces in fact, and they contain the stumps of cycadaceous trees which the quarrymen now call 'birds'-nests'. Although the Purbeck fossils are mostly of fresh-water or lacustrine species such as *Paludina*, *Cypris Purbeckensis*, *Archæoniscus Brodiei*, &c., yet occasional beds of oysters (*Ostrea distorta*) occur, which are locally known as 'Cinder-beds', and which mark the occasional influx of salt or brackish water. Remains of insects are not uncommon, and a quarry near Swanage has yielded teeth, &c., of more than twenty species of small marsupial mammals.

The Oolites of Yorkshire.—In the north-east of Yorkshire the strata of Lower Oolitic age are mostly sands and sandstones in which two or three thin coal-seams occur. They are locally called the "Dogger series", because they contain rounded concretionary masses of sandstone—'dogger' being a term used in that district for any large round stone. The coal-seams in the Yorkshire Oolite have been occasionally worked, but they yield a very poor fuel.

Economic Products.—The limestones of the Oolite are very largely quarried for building-stone round Bath, and at Portland, &c.

In Northamptonshire the *Inferior Oolite* sandstone has been largely worked for iron-ore.

The Yorkshire Oolites contain a few thin seams of coal, though but of poor quality.

Summary of the Oolites.—The Oolites of the Centre and South of England consist in the main of alternations of clays and limestones, the latter often having an oolitic or 'grainy' structure. The thick clay-beds were probably deposited in deep but muddy seas; and the limestones in shallower and clearer waters. Land evidently lay to the north during the deposition of these rocks; and accordingly we find two types of Oolitic strata in England—the first in Dorset, Wilts, Oxford, Bucks, and Lincolnshire, where marine conditions prevailed, and the second in the north-east of Yorkshire, where a large river entered the Oolitic sea. The sands, shales, and grits with their included plant remains which constitute the Yorkshire Oolite were accumulated in and near the estuary of this northern river.

The climate of the Oolitic Period must have been warm; and all things were favourable to life. Coral-reefs grew in the sea, and sea-urchins (echinoderms), brachiopod and gasteropod shells, with ammonites and belemnites (cephalopods), and fish swarmed over and around them.

On the land, coniferous trees represented the highest forms of vegetation; and around them grew ferns, cycads, and horsetails.

Fig. 124.—Ideal Restoration of life of Lower Oolite. A marsupial is climbing a tree; while Ichthyosaurs and the long-necked Plesiosaurs occupy the waters.

Small insect-eating marsupials were the most highly organized animals then existing; but there were Dinosaurian reptiles of immense size—the *Megalosaurus* and the *Cetiosaurus*—whose bones show them to have attained a length exceeding thirty feet. Some of these Oolite reptiles have the hind limbs so strongly developed as compared with the fore limbs that they must have walked or hopped on their hind legs like kangaroos.

A remarkable flying reptile—the *Pterodactyl* (see fig. 120)—might have been seen in the air; but in the Solenhofen Limestone (*Upper Oolite*) of Germany the remains of a bird have been found—*Archæopteryx macrura*—which (although a true bird) united in a remarkable way certain of the characteristics of birds and of reptiles.

Finally, at the close of the Oolitic period elevation again took place, the greater part of the British Isles once more became dry land, and the Purbeck Beds of the south of England were deposited in a fresh-water lake.

CHAPTER XXX.

The Cretaceous Formation

(Including the Wealden).

Why called Cretaceous.—We have next to describe a set of strata which, although grouped together because they have certain general characters in common, yet include both sands, clays, and limestones. But of these by far the most remarkable, the most characteristic, and the best known to us is the thick bed of soft nearly pure earthy limestone which we call *Chalk*. From this rock (Lat. *creta*, chalk) we derive the name of Cretaceous, which is applied to the entire formation or group of strata of which our White Chalk is the most conspicuous member.

How the Cretaceous Formation is subdivided in Britain.—The close and long-continued study of many years

has enabled British geologists to separate the Cretaceous rocks (altogether 4000 feet in thickness) of this country into the following subdivisions:

TABLE OF THE CRETACEOUS FORMATION.

		Feet.
Upper Cretaceous	White Chalk, with Flints,	600
	White Chalk, with few or no Flints,	400
	Chalk Marl, or Gray Chalk,	80
	Chloritic Marl,	20
	Upper Greensand,	200
	Gault,	100
Lower Cretaceous or Neocomian	Lower Greensand,	500
	Wealden Beds,	2100

The Change from the Jurassic to the Cretaceous Epoch.—We have seen that the highest Jurassic strata—the *Purbeck Beds*—were deposited in the waters of a lake or lagoon which had been formed in the south of England by the steady uprising of the floor of the Oolite sea. This elevation, though steady, was not everywhere equal in amount, nor was the sea everywhere of equal depth. Thus portions of the sea would be cut off from the main body of water, and lagoons would be formed.

Now this is just what had previously happened in Permian and in Triassic times; but there was a great difference between these two epochs and the era of which we are now treating in the fact that the climate of this country was during the earlier epochs (Permian and Triassic) apparently dry if not rainless; while in the later Purbeck and Wealden times it was moist and rainy. Thus the Purbeck lagoons, instead of becoming pools of intensely salt water, were continually diluted by rain and rivers, and became brackish lakes.

As time passed on more and more fresh water was poured by rivers, &c., into this old Purbeck lake; it greatly extended its boundaries, fresh-water species of animals and plants inhabited it, and in it were deposited the beds of clay and sand which we now call the *Wealden Beds*.

LOWER CRETACEOUS OR NEOCOMIAN.

The Wealden Beds.—That part of the south-east of England lying between the North and South Downs has long been called "The Weald" (from *weald* or *wold*, Anglo-Saxon for a wooded hill); and the strata which compose it were named 'Wealden' by Martin, who with Mantell and Fitton first carefully studied them, between 1820 and 1830, in the counties of Kent, Surrey, and Sussex.

The strata which occupy the central part of this area, from Horsham on the west by Tunbridge Wells to Hastings on the east, are mostly sandy in nature, and are called the *Hastings Beds.* They form hilly ground (Crowborough Beacon, 803 ft., is the highest point) and give rise to some picturesque scenery.

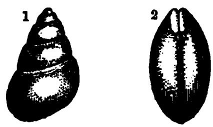


Fig. 125.—(1) *Paludina Sussexensis* (a fresh-water gasteropod); (2) *Cypris Valdensis* (a fresh-water crustacean); from the Wealden.

Encircling the Hastings Beds we have the *Weald Clay*, which forms a low tract of heavy wet soil running from Hythe to Haslemere, and thence to Pevensey.

The total thickness of these Wealden Beds is about 2100 feet; they also occur in Dorset and in the Isle of Wight.

The fossils show the Wealden strata to have been deposited in the estuary of a great river. They include many plant-remains—including conifers, cycads, and ferns; together with such genera of fresh-water molluscs as *Cyrena*, *Unio*, *Paludina*, &c., and immense numbers of a little bivalved crustacean called *Cypris* (see figs. 123, 125).

Beds of clay ironstone also occur, which were worked until the Weald hills were denuded of their timber for fuel; the last iron furnace of the south east of England, that at Ashburnham, was blown out in 1828. There are remains of fishes also in the Wealden Beds; but by far the most remarkable fossils found in these rocks are the reptiles, which include the *Iguanodon*, whose length is estimated at upwards of 40 feet.

In north-east Yorkshire at the same time, marine conditions

prevailed, and the Wealden Beds are represented there by the *Lower Speeton Clay*, 230 ft. thick.

The Lower Greensand.—After many ages (during which the Wealden Beds were gradually deposited) this part of what is now Western Europe was slowly depressed below the level of the sea, and greenish sands, with occasional bands of clay, limestone, and ironstone were laid down upon and above the estuarine strata of the Wealden. These marine beds are now thickest in Hampshire (800 feet), but they thin considerably when we follow them to the east and north-east, being but 320 feet thick at Sevenoaks, and only 31 feet thick

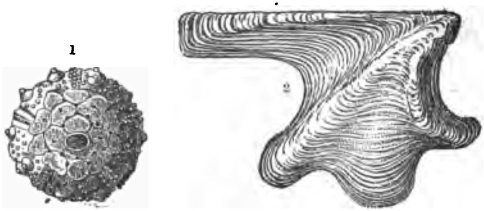


Fig. 126.—(1) *Salenia punctata* (sea-urchin), Lower Greensand; *Perna Mulleti* (lamellibranch), Atherfield and Speeton Clays.

beneath Dover. They can be traced to the north-east by Oxford and Wobùrn into Norfolk (where they are called "Carstone"). In Yorkshire the Lower Greensand is represented by the *Upper Speeton Clay*, 270 feet in thickness.

The Lower Greensand fossils are all of marine species, and include *Ammonites Deshayesii*, *Perna Mulleti*, &c.

Neocomian Strata.—Some geologists use the name Neocomian for the whole of the Lower Cretaceous strata, including the Wealden Beds and the Lower Greensand. The term is derived from *Neocomium*, the old Latin name of the town of Neuchatel in Switzerland, in whose neighbourhood rocks of this age are well developed and exposed.

Upper Cretaceous.

The Gault.—To a bed of stiff clay, from 100 to 200 feet in thickness, which rests unconformably on the Lower Green-

sand, the name of *Gault* had long been applied by navvies, and the term was adopted as a geological name by Michell, in 1788. The Gault is well exposed in the Folkestone cliffs; in the Isle of Wight it is known as 'the Blue Slipper', for the water which soaks through the sandy beds above issues as springs at their junction with the impervious gault clay: the plane of junction being thus eroded, great masses of the upper beds occasionally slip down; the famous 'Undercliff' and the 'Landslip' near Ventnor and Bonchurch, for example, have thus been formed.

Traced westward the Gault is only 25 feet thick at Lyme Regis; it extends thence north-east by Devizes and Cambridge into Norfolk, where it is seen in the cliff at Hunstanton-on-the-Wash as a band of red limestone (the so-called "Red Chalk") 4 feet in thickness.

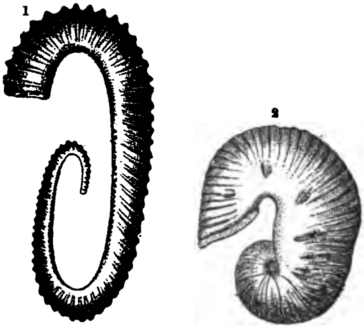


Fig. 127.—(1) *Hamites rotundus* and (2) *Scaphites æqualis*, two cephalopods from the Gault.

The Gault contains a large number of beautiful fossils, which are, however, difficult to preserve, having a tendency to crumble to pieces as they dry. To prevent this they should be coated with, or soaked in a weak warm solution of gelatine. The species are all marine, and include the four cephalopods *Ammonites splendens*, *Belemnites mininus*, *Hamites rotundus*, and *Scaphites æqualis*, together with corals, fish remains, &c. (see fig. 127).

The Upper Greensand.—As its name implies, this bed consists for the most part of sands and sandstone tinged green by the mineral *glauconite*. In the Wealden district it is 60 feet thick, and it is there known as 'Firestone' or 'Malm Rock'. It extends westward to the Blackdown and Haldon Hills in Somerset and Dorset, and can be traced thence in a north-easterly direction by Swindon and Wallingford.

The fossils include many sponges, whose remains in the Blackdown Hills form beds of *chert* (an impure variety of flint); the shells *Pecten asper* and *Ammonites inflatus* are characteristic Upper Greensand species.

Range of the White Chalk.—The soft earthy limestone we call chalk forms those white cliffs on the coasts of Sussex and Kent which, long ago, secured for England the name of 'Albion'. The Chalk is here about 800 feet thick, and forms

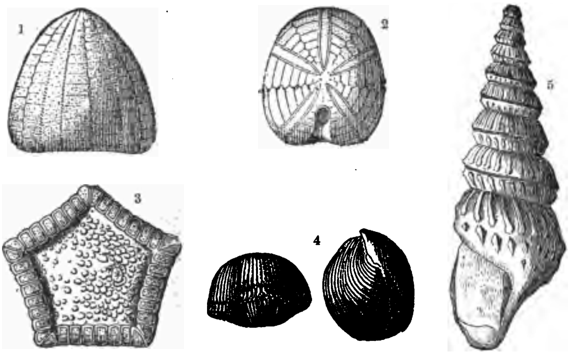


Fig. 128. — (1) *Galerites albogalerus*, and (2) *Nucleolites dimidiatus*, two sea-urchins (echinoderms); (3) *Goniaster Coombii* (star-fish); (4) *Rhynchonella octoplicata* (brachiopod); (5) *Turrilites costatus* (cephalopod). All from the White Chalk.

the two ridges called the North and South Downs. The strata of these hills were once continuous, forming a broad anticlinal or 'saddle-back', which stretched right over the now intervening Wealden district; but the agents of denudation — rain, rivers, frost, &c.—have removed the chalk, &c., from the top and centre of this anticlinal.

The chalk which forms the North Downs dips to the north, passes under London (where it yields an ample supply of good though hard water to many deep wells), and rises up again to form the Chiltern Hills, and extends north-eastwards to Norfolk and the Wash. There the chalk curves round to form the Lincolnshire and Yorkshire Wolds, and finally it runs out to sea at the bold promontory of Flamborough Head.

The chalk of the South Downs dips to the south under the

Solent, and rises up again to form the 'Downs' of the Isle of Wight.

Traced to the west the chalky strata of the North and South Downs unite in Hampshire and form a broad tract round Winchester, Salisbury, and Marlborough, including Salisbury Plain, upon which stands the grand prehistoric stone circle of Stonehenge.

In Antrim in the north-east of Ireland, and in the Hebridean isles of Mull and Morven, the White Chalk (here only from 10 to 100 feet in thickness) is found below great sheets of basalt, by which it has been hardened and altered.

Subdivisions of the White Chalk.—The base of the chalk is clayey, the lowest bed or *Chloritic Marl* being so named from the numerous dark-green grains of the mineral *glauconite* which it contains; it is characterized by the cephalopod shells *Scaphites æqualis* and *Ammonites Rothomagensis*. Above it comes the Chalk Marl or Gray Chalk, in which the limestone is still mixed with a certain amount of clay; but above this we have the great mass of the true White Chalk, a rock which contains from 95 to 98 per cent of carbonate of lime, and whose total thickness in Britain is as much as 1200 feet. In the *lower* half of this remarkably thick stratum, flints either seldom occur or are altogether absent; in the *upper* half they are common.

Origin of the White Chalk.—Take a piece of chalk and brush it vigorously with a tooth-brush in a glass of water until the liquid looks quite milky. Allow the greater part of the sediment to subside, and then pour away the water and wash the material which has sunk to the bottom of the glass by pouring water on it two or three times. Put the whitish powder which finally remains under a microscope; and examine it with, say, the quarter-inch power, which will magnify about 300 diameters. The greater part of the white powder will then be seen to be composed of the minute shells of creatures called Foraminifera—little specks of jelly-like matter which secrete for themselves a shell or covering from the carbonate of lime dissolved in the sea-water in which they live.

Countless millions of foraminifera inhabit the waters of the North Atlantic (and of other deep seas) at the present day; and of these at least one species—*Globigerina bulloides*—cannot be distinguished from one of the commonest species found in the White Chalk. When these tiny animals die, their soft parts soon decay and disappear, and their skeletons (or shells) fall on the sea-floor, where they form a whitish mud or 'ooze' in which the Anglo-American telegraph cables lie securely.

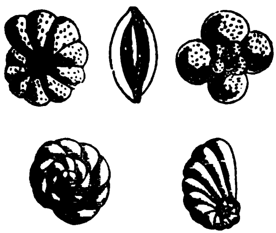


Fig. 129.—Foraminifera from the Chalk (highly magnified).

Thus everything points to a continuous subsidence from the time of the Purbeck-Wealden continent until the formation of the White Chalk in a deep sea. The time required for the accumulation of so thick a deposit composed of the remains of organized beings—the White Chalk is in Norfolk quite 1200 feet thick—must have been very great. If we allow that the tiny shells of the foraminifera may have accumulated at the rate of two feet in thickness in a century, then it would have required 50,000 years to form the chalk of the south-east of England, whose thickness we have estimated at 1000 feet.

COMPARISON BETWEEN THE GLOBIGERINA OR FORAMINIFERAL OOZE OF THE NORTH ATLANTIC, AND THE CHALK MARL OF SURREY.

Chemical Analysis of Globigerina Ooze from North Atlantic. Collected, March 21st, 1876. Depth = 1990 fathoms.

		Per cent.
Portion Soluble in Hydrochloric Acid = 97·11 %.	Calcium Carbonate,	92·54
	Magnesium Carbonate,	0·87
	Calcium Sulphate,	0·19
	Calcium Phosphate,	0·90
	Silica,	1·36
	Alumina,	0·65
	Ferric Oxide,	0·60
		97·11
Portion Insoluble in Hydrochloric Acid = 1·49 %.	Alumina, Ferric Oxide, Silica,	1·49
	Loss on drying at 230° F. =	1·40
	Total,	100·00

Chemical Analysis of Chalk Marl from the extreme west corner of Surrey.

		Per cent.
Portion Soluble in dilute Acids = 92·74 %.	Carbonate of Lime,.............	87·89
	Magnesia,.........................	1·18
	Potash,.............................	0·11
	Soda,................................	1·37
	Oxides of Iron,....................	1·84
	Alumina,............................	0·20
	Sulphuric Acid,....................	0·06
	Phosphoric Acid,.................	0·05
	Chlorine,...........................	0·04
		92·74
Portion Insoluble in dilute Acids = 7·26 %.	Lime,................................	0·22
	Magnesia,..........................	trace
	Potash,..............................	0·15
	Soda,................................	0·05
	Alumina,............................	1·42
	Sand, and a little Oxide of Iron,	5·42
	Total Insoluble, =	7·26
	„ Soluble. =	92·74
		100·00

From a study of the above analyses it will be observed that a small portion of the calcium carbonate, or carbonate of lime, of the Chalk Marl has in all probability been removed by percolating waters. Also that the proportion of insoluble matter is slightly greater in the Chalk Marl than in the Atlantic ooze. But allowing for these minor discrepancies there is a striking resemblance between the two deposits from a chemical point of view, and the Chalk Marl and the White Chalk above it were probably formed under conditions very similar to those which now prevail at the bottom of the North Atlantic Ocean.

The Flints in the Chalk.—Flints are lumps or nodules of amorphous silica, which commonly occur in the Upper White Chalk in distinct layers a few feet apart. Each flint frequently surrounds or envelops some organism, as a sponge, a shell, &c. During the formation of the chalk the sea-floor appears to have been covered, at intervals, by a growth of sponges, which were composed of siliceous matter, and their death and decay produced most of the flint. Sometimes flint is found in bands or

layers; in which case it may have been deposited from water (which contained it in solution) as the water trickled through fissures in the chalk rock.

Fossils of the White Chalk.—Since chalk is largely composed of the extremely small shells of foraminifera, it may be said to be 'made of fossils'; and it is therefore called an 'organically-formed rock'. But there are many other fossil remains in the chalk, including sea-urchins, such as *Holaster planus*, *Ananchytes ovatus*, *Micraster cor-anguinum*, *Galerites albogalerus* (fig. 128), &c.; cephalopods, as *Belemnitella mucronata*; brachiopod shells, as *Rhynchonella Cuvieri*; lamellibranchs, as *Inoceramus Lamarckii*, &c.; fishes, as *Beryx ornatus*; and reptiles.

Economic Products.—The pure white limestone of the chalk is largely burnt into *lime*; it is also used in the manufacture of *whitening*. The flints are used in building, and in the manufacture of porcelain. Bands of phosphatic nodules or 'coprolites' occur in the Greensands, which are ground up and used to make artificial manure.

Phosphatic Chalk.—Above the Chalk Marl, and in the White Chalk there has recently been found at Taplow, near London, a band of phosphatic chalk, containing phosphatized foraminifera, fish-scales, fragmentary fish-bones, and minute coprolites. From a commercial point of view this deposit is of value, the calcium phosphate or phosphate of lime being one of the most valuable of artificial manures. In France similar bands of phosphatic chalk have long been worked; but unfortunately the band at Taplow is not thick enough nor continuous enough to pay for working.

Summary of the Cretaceous Formation.—The Cretaceous strata include clays and sandstones in their lower part; but they are named *Cretaceous* because the white earthy limestone we call chalk is the most important stratum of all.

From beginning to end the Cretaceous epoch was one of slow but steady subsidence in this part of the world: so that the lacustrine deposits which form the Wealden were succeeded by the shallow seas in which the Greensands and the Gault were deposited, and finally we get the deep-sea conditions

evidenced by the White Chalk. This change is proved, partly by the nature of the rocks, and partly by the fossils which they contain. The climate seems to have been warm and temperate; and it is probable that land lay to the north, stretching across where the Atlantic Ocean now rolls, and so preventing any cold currents from the regions round the North Pole from entering the Chalk Ocean.

Every cubic inch of ordinary White Chalk contains millions of the tiny perforated shells of foraminifera, microscopic animals which flourished in countless myriads in the Cretaceous seas, and which still inhabit our oceans. Some of the living forms are indistinguishable from those species which helped to make the chalk.

SECTION M.

THE CAINOZOIC SERIES; INCLUDING THE TERTIARY AND THE QUATERNARY SYSTEMS.

CHAPTER XXXI.—THE TERTIARY SYSTEM.

THE EOCENE FORMATION OR LOWEST TERTIARY.

Unconformity at the top of the British Chalk.— Above the White Chalk we have in England a series of clays and marls, sands, gravel-beds, &c., which are comparatively loose, soft, and unconsolidated. These lie *unconformably* upon the chalk. The line of junction is, moreover, very *abrupt*, and the change from the deep-sea limestone (as we know chalk to be) to shallow-water sands is *sudden*. There is also evidence that the upper beds of the Chalk were in England much *eroded* or worn away before the beds which now lie upon them were deposited. All these facts point to a *great interval of time* as having elapsed between the deposition of the Chalk and of the strata which now rest upon it.

Elsewhere, however, on the Continent and in North America, strata several thousand feet in thickness are found, which completely fill up and bridge over this interval.

Change of Life at the end of the Mesozoic Period.—Of the thousands of *species* of animals and of plants which have been found fossil in Mesozoic strata, one only (a shell called *Terebratula striata*) is known to have survived in this region until the succeeding Tertiary epoch. This great change of the flora and fauna would of itself alone point to a great gap or interval of time between the Secondary or Mesozoic and the Tertiary or Cainozoic strata; for such changes in the animals and plants of any region take place only with extreme slowness and by degrees.

Nomenclature of the Newer Rocks.—The early geologists applied the name of TERTIARY—third in order of succession—to *all* the strata which are newer than the Chalk. Later researches have shown that it is better to divide these rocks into two parts—an older and lower, to which the name of Tertiary is now restricted; and an upper and newer, which is styled the QUATERNARY, or Fourth series.

But it is still very useful to have a name which shall include both the Tertiary and the Quaternary strata, and which shall apply in fact to every rock that has been formed *since* the deposition of the Cretaceous beds. For this purpose we use the word CAINOZOIC, a term derived from the Greek *kainos*, recent; and *zoe*, life. This name expresses the fact that in the strata which lie above the Chalk, we meet *for the first time* with fossils which are identical with *still living* species of animals and plants.

Classification of the Cainozoic Rocks.—The total thickness of the strata deposited in England since the Cretaceous Epoch is only about 3000 feet. But the beds have been studied with such care, and their fossils are so abundant and well preserved, that the numerous subdivisions shown in the table on p. 281 have been clearly made out.

THE TERTIARY SYSTEM.

THE EOCENE FORMATION.—The oldest and lowest Tertiary strata were termed "Eocene" by the late Sir Charles Lyell in

TABLE OF CAINOZOIC STRATA.

QUATERNARY OR POST-TERTIARY	RECENT, or Superficial and Post-glacial Deposits.	
	GLACIAL BEDS or "Drift" (also called Pleistocene).	
TERTIARY	PLIOCENE	Cromer Forest Bed.
		Norwich Crag.
		Red Crag.
		Coralline Crag.
	MIOCENE	Absent from Britain.
	OLIGOCENE	Hempstead Beds.
		Bembridge Beds.
		Osborne Beds.
		Headon Beds.
	EOCENE	Bagshot, Bracklesham, and Bovey Tracey Beds.
		London Clay and Bognor Beds.
		Oldhaven Beds.
		Woolwich and Reading Beds.
		Thanet Sands.

1830. The name Eocene (Greek *eos*, the dawn; and *kainos*, recent) implies that the strata to which the name is applied contain the first fossils which are identical with species of animals or plants now living. About 3½ per cent—or one in thirty—of the Eocene species still exist.

The Eocene beds of the British Isles occur almost exclusively in two synclinal curves or basins—those of London and Hampshire respectively.

The Thanet Sands are found in the London Basin only. They consist of about 60 feet in thickness of greenish sands, well exposed in the Isle of Thanet. They contain a few marine fossils, among which *Cyprina Morrisii* is a common lamellibranch shell.

The Woolwich and Reading Beds, which come next, are sands and clays, which contain evidence to show that they were formed in and near the mouth of a great river, whose course was roughly similar to that of our Thames. At Woolwich they contain such marine shells as *Ostrea bellovacina*; but further west, at Reading, they are unfossiliferous. Both these beds and the Thanet Sand with the Chalk beneath are finely exposed in the deep ballast-pits at Charlton, near Woolwich, and at Loam Pit Hill, near Lewisham.

In the Hampshire Basin the Woolwich and Reading Beds extend from Arundel to Chichester and Cranborne on the north. Dipping to the south they pass under the Solent, and rise up again in the Isle of Wight, forming a strip right across the island from Alum Bay to Whitecliff Bay.

The Oldhaven Beds are masses of rolled flint pebbles, altogether only 30 feet in thickness. They form Blackheath and Plumstead Common, near London. Sometimes the pebbles are cemented together so as to form a conglomerate.

The London Clay is a stiff brown or bluish clay, which forms much of Middlesex and Essex. It is 480 feet thick in South Essex. It is exposed in many brick-yards near London; but fossils are scarce in it, or at least are confined to certain bands or horizons. In the Isle of Sheppey the London Clay abounds in fossil leaves and fruits of palms, such as *Nipadites umbonatus* (fig. 130); remains of turtles, too, are common, and fossil wood full of the holes of a boring bivalve shell, the *Teredo*. Marine shells, such as *Nautilus imperialis*, *Voluta nodosa*, *Conus*, *Cypræa*, &c., are found, mixed with the bones of tapirs, crocodiles, and opossums. The remains of a very remarkable bird (*Odontopteryx toliapicus*, the toothed bird of Sheppey) have also been met with. Its bill was provided with numerous bony projections (resembling teeth) which aided it in securing the slippery fishes on which it fed.

Fig. 130.—*Nipadites umbonatus*, a fossil palm-fruit from the London Clay.

All this points to the fact that the London Clay was laid down in a shallow sea, close to the mouth of a large river running from the westward.

The Bognor Beds of the Hampshire Basin, which occur at Bognor, Chichester, Portsmouth, and also in the Isle of Wight, are shown by their position and by their fossils to be of about the same geological age as the London Clay.

The Bagshot Beds form the well-known heath of that name in Berkshire, where they are seen as unfossiliferous sands 100 feet thick.

In the Hampshire Basin the Bagshot Sands are represented by the Bracklesham Beds and the Barton Clay, which contain numerous marine shells, as *Cardita planicosta*, *Voluta spinosa* and *Oliva Branderi* (fig. 131). At Bournemouth they contain seams of clay, in which numerous leaves of oak, fig, pine, &c., are found. In the Isle of Wight they form the brightly-coloured sands of Alum Bay.

Further west, at Bovey Tracey in Devonshire, are beds of sand and clay about 200 feet in thickness, which were clearly formed in the bed of an old lake. They contain numerous

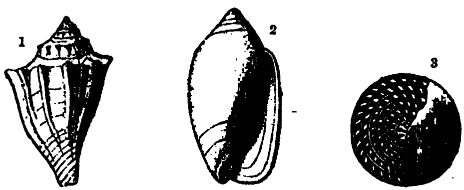


Fig. 131.—(1) ***Voluta spinosa*** **(gasteropod) from Bracklesham Beds; (2)** ***Oliva Branderi*** **(gasteropod) from Barton Clay; (3)** ***Nummulites lævigata*** **(foram.) from Bagshot and Bracklesham Beds.**

plant-remains of conifers, oaks, vines, figs, laurels, ferns, &c. Seams of lignite (wood-coal) occur, which have been worked as "Bovey Coal" ever since 1714.

In the island of Mull (W. Scotland), and in the basaltic region of Antrim and the Giant's Causeway in the north-east of Ireland, thin beds of old soil or earth are found interstratified with the volcanic rocks. In these earth-beds the Duke of Argyll found leaves, &c. in 1851, which prove the strata to be of about the same age (Middle Eocene) as the leaf-beds at Bournemouth and at Bovey Tracey.

Summary of the Eocene Formation.—In the British Isles there is a wide break, or gap, or interval of time between the deposit of the highest beds of the White Chalk and the lowest layers of the Tertiary strata. Not only are the latter unconformable in stratification to the former, but they contain an entirely different fauna and flora.

The White Chalk was formed in a deep sea, and the Creta-

ceous Epoch was brought to a close by the elevation of that old sea-floor; and doubtless many of the top beds of the Chalk were eroded or worn away by the action of the sea while they were being slowly raised above the water.

In the British Isles the Eocene beds occur almost exclusively in the south and south-east of England, where they occupy two distinct areas or 'basins'—the London Basin and the Hampshire Basin respectively, the latter including the northern half of the Isle of Wight. In the London Basin the total thickness of the Eocene strata (taking each bed where it is thickest) is under 1000 feet; but in the Hampshire Basin it is about double this amount.

Land lay to the north and west; and in the 'leaf-beds' of Antrim and Mull we have preserved to us some of the soil of that old land, buried beneath lavas and ash-beds ejected from volcanoes (equal in size at least to Etna and Vesuvius) which were then in full activity.

Of a great Eocene river running from the west right across the south of England we have evidence in the Bovey Tracey Beds (probably deposited in a lake through which the old river flowed) and in the fresh-water and estuarine strata which form much of the Bagshot and Bournemouth Beds. The London Clay was formed in a shallow sea near the mouth of this river.

The Eocene fossils found in Britain include about 1500 species of animals and plants, and they indicate a decidedly warm or 'subtropical' climate.

CHAPTER XXXII.

The Oligocene Formation

(Formerly called "Upper Eocene").

Meaning of the name "Oligocene".—The word *oligocene* is derived from the Greek *oligos*, few; and refers to the fact that but *few* of the species, or even genera, of its fossils belong to forms still living.

Occurrence of Oligocene Strata in Britain.—The Oligocene beds are found in Britain only in the south of England; occurring there in the New Forest, in Hampshire. Dipping southwards under the Solent they rise up again to form the northern shores of the Isle of Wight.

The English Oligocenes consist of marls, clays, and sands, with occasional beds of limestone, and appear to have been formed partly in fresh, partly in brackish or even salt water, in or near the mouth of a large river: their total thickness is about 500 feet.

Four subdivisions have been made out in the Oligocene strata of Britain, and these have been named after four places—Headon, Osborne, Bembridge, and Hempstead or Hamstead—in the Isle of Wight, where the strata of each subdivision are in turn well exposed. The soft cream-coloured "Hempstead limestone" is about 20 feet thick; it has been worked for centuries (as building-stone) in the quarries at Binstead, near Ryde.

Oligocene Fossils.—About 120 species of fossils have so far been obtained from the Oligocene Formation in England:

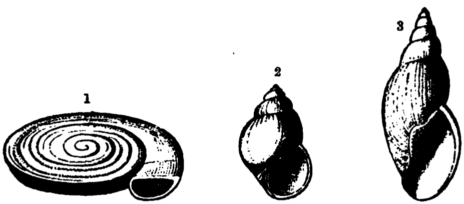


Fig. 132. (1) ***Planorbis euomphalus*** **(gasteropod) from Headon Beds; (2)** ***Paludina lenta*** **(gasteropod) from Hempstead Beds; (3)** ***Limnæa longiscata*** **(gasteropod) from Headon Beds.**

of these 52 are gasteropod shells, and 30 are bivalves. The seeds of a fresh-water plant—*Chara tuberculata*—are common, with such fresh-water gasteropod shells as *Paludina lenta*, *Limnæa longiscata*, and *Planorbis euomphalus* (fig. 132). There are gasteropod land-shells, too—*Bulimus*, and *Helix*—while the occasional presence of bands of such marine lamellibranch shells as *Venus incrassata* shows that the land was sometimes invaded by the sea.

But the most remarkable fossils of the Oligocene strata are the bones of *large* mammals, which are here met with for the first time. They mostly belong to a creature resembling the tapir, which has been named the *Palæotherium.*

Summary of the Oligocene Formation.—The Oligocene strata of England were formerly known as the "Fluvio-Marine Series". They were formed in the delta of a river which ran through Hampshire and the Isle of Wight, draining land which lay to the north and west. The strata exceed 500 feet in thickness, and contain many species of fresh-water, brackish-water, and even a few marine shells; there are also land-shells, swept into the river by rains or floods, and bones of crocodiles and turtles, together with those of a few large mammals. Rushes and reeds, ferns and palms, grew on the banks and muddy flats of the old river, and occasionally became buried and preserved in its mud or sand. The climate was probably temperate, but not so warm as that of the Eocene Period. During the Oligocene Period Britain was gradually upheaved, and at its close the land was probably at a much higher level than at the present time.

The Miocene Formation.

Absence of Miocene Strata from Britain.—Only a few years back the Bovey Tracey Beds, together with the Leaf-beds of Mull and the Hempstead Beds of the Isle of Wight, were regarded as of Miocene age. A more complete examination of the strata, and the study of new and large collections of their fossils have, however, shown that the Hempstead (or Hamstead) Beds should be classed with the Oligocene Formation, in which we have accordingly placed them; while the Bovey Tracey Beds of Devonshire, and the Leaf-beds of Mull, have been shown by Mr. J. S. Gardner to be of the same age as the well-known plant-beds of Bournemouth, *i.e.* to belong to the Bagshot (Eocene) Beds.

Use of the name "Miocene".—The term *Miocene* is derived from the Greek *meion*, less, and *kainos*, recent; and it

must be compared with the term *Pliocene* (from *pleion*, more; *kainos*, recent), which is applied to the next set of strata above the Miocene.

In the Miocene strata, as seen in Italy, Austria, &c., the fossils still belong more frequently to *extinct* than to living species; while in the Pliocene strata the contrary is the case.

Condition of Britain during Miocene Times.—No deposits of Miocene age have been found either in Britain or the adjoining parts of Northern France. This implies that this country remained as dry land during the Miocene Period. In Central France the now extinct volcanoes of the Auvergne district were actively erupting during Miocene times; and from Miocene strata in Greenland numerous fossil plants have been obtained which show the climate to have been much warmer than at the present day.

CHAPTER XXXIII.

The Pliocene Formation.

Areas occupied by the British Crag.—The strata we have next to describe have long been familiarly known as the *Crag* (from the Celtic word *creggan*, a shell), because of the great abundance of fossil shells which they contain. Lyell named them the "Pliocene Beds" in the first edition of his famous book, *The Principles of Geology*, published in 1830. The Crag proper is found on the east coast of England as a narrow strip extending from Walton in Essex to Aldborough in Suffolk. It also occurs inland at Bramerton near Norwich; and two small outlying patches are known, one at St. Erth in Cornwall, and the second at Lenham, on the North Downs in Kent.

Subdivisions of the Crag.—Six subdivisions have been recognized in the Pliocene strata of England. As these subdivisions are not all present in any one locality, it follows that the fossils which they contain must be our principal guide as

to their relative ages. We consider, of course, those beds to be the oldest which contain the largest proportion of extinct species.

TABLE OF THE PLIOCENE STRATA.

		Feet.
NEWER PLIOCENE.	Cromer Forest Bed Group,	30
	Norwich Crag,	120
	Red Crag,	40
OLDER PLIOCENE.	White or Coralline Crag,	80
	St. Erth Beds,	?
	Lenham Sands,	?

Characters of the Pliocene Strata of Britain.—The oldest Pliocene rocks of this country are probably the *Lenham Sands*, which are found in pipes or hollows in the chalk of the North Downs. They have yielded about twenty species of fossils, including the brachiopod shell *Terebratula grandis*. These Lenham beds doubtless once extended all over Kent and Surrey, but the greater part of them has been removed by denudation.

The *St. Erth Beds* occupy a hollow in the old slaty rocks north of Penzance in Cornwall. They are clays and sands in which fossils have only lately been found, but these fossils include species of such shells as *Nassa*, *Turritella*, *Cerithium*, &c., some of which are found in the Miocene Beds of the Continent, but more are also common in the "Crag" of the Eastern Counties.

The White or Coralline Crag is well exposed in Suffolk, round Woodbridge, Orford, &c. It is a yellow sandy or calcareous rock, very full of the remains of what used to be called "corallines", but which are not corals at all—belonging in reality to the *Polyzoa* or coral-like Molluscoida. It has also yielded 317 species of shells, of which 264 (or 84 per cent) can be identified with shells now living. *Voluta Lamberti* (a gasteropod) and *Astarte Omalii* (lamellibranch) are characteristic shells. Most of the shells belong to such species as now live in warm or temperate seas; but mingled with them are a few which we now find living in Arctic and Scandinavian waters.

The Red Crag owes its name to the way in which its sands are coloured dark-red by peroxide of iron. It is well

seen at Walton-on-the-Naze, in Essex, where it rests on the London Clay; but near Ipswich and Aldborough, further north, it has the Coralline Crag beneath it. At its base Professor Henslow discovered a bed of brown phosphatic nodules, which have been miscalled "coprolites", and which have been largely worked to make into an artificial manure.

Fig. 133.—*Trophon antiquum* (gasteropod) from the Red Crag.

As examples of well-known Red Crag fossils we may name the shells *Trophon antiquum* (fig. 133), *Pecten opercularis* (a lamellibranch), *Nassa granulata* (a gasteropod), &c. Altogether 234 species of shells have been obtained from the Red Crag, of which 216 (or 92 per cent) belong to yet living species.

The Norwich Crag is well seen at Thorpe and Bramerton near Norwich, where its fossiliferous light-coloured sands rest upon the Chalk. Its basement bed contains many large flints, and is therefore called the "Stone-bed", besides bones of several large mammals, including the mastodon (*Mastodon arvernensis*), and an extinct species of elephant (*Elephas meridionalis*). The shells are numerous (139 species), and 130 species (or 93½ per cent) can be identified with still living forms. Here, for the first time, species of shells such as now live in cold northern seas predominate, including *Astarte borealis*, *Cyprina Islandica*, *Nucula Cobboldiæ*, &c.

The Cromer Forest Bed Series is exposed at the base of the cliffs at Cromer in Norfolk, and at intervals along the coasts of Norfolk and Suffolk. It includes layers of sand, clay, and gravel; its upper surface has the appearance of an ancient soil, being penetrated by rootlets, and containing many stumps of trees. The whole is of fresh-water and estuarine origin. The plant *Naias marina*, the seeds of which have been found in the Cromer Forest-bed, is now found living at only one locality in Britain, viz. in Hickling Broad, Norfolk. This Forest-bed of the Norfolk coast has yielded a finely-preserved skull of a gigantic extinct Beaver-like animal (*Trogontherium*), remains of which have also been found in Siberia and in France. Alto-

gether the bones of about fifty species of mammals occur in the Forest-bed, including several extinct species of elephant (*Elephas meridionalis* and *E. antiquus*), and of rhinoceros (*Rhinoceros etruscus*), &c.

Summary of the Pliocene Formation.—At the close of the Miocene Epoch, the south-east of England was submerged until the sea covered places (as the North Downs of Kent) which are now 600 feet above it. The Pliocene strata were accumulated as shell-banks and shore deposits in this shallow sea.

At the commencement of this epoch the climate was moderately warm, for the shells of the White or Coralline Crag bear a general resemblance to those of the Mediterranean; but it gradually grew colder as time passed on. The result was that the number of shells which flourish best in cold waters gradually increased, while the southern forms died out, until in the Norwich Crag the former preponderate. All this was due, as we shall explain in the next chapter, to the steady on-coming of that period of intense cold which we designate the Glacial Period or Great Ice-Age.

GENERAL SUMMARY OF THE TERTIARY SYSTEM.

The strata which compose the Tertiary formations are remarkable for the recent character of the fossil forms which have been found within them. This is most apparent in the invertebrate forms of life, such as the oysters and the gasteropods; while the lamellibranchs greatly outnumber the brachiopods.

Even in the oldest Tertiaries there are found some species of molluscs which still exist; and in the Newer Tertiaries a very large proportion of the molluscan fauna survives to the present day. The greatest contrast to the life of the present day is presented by the Tertiary Vertebrata; the gigantic *Deinotherium* and the *Palæotherium* being quite unlike any animals now living.

The stratified rocks of the Palæozoic and Mesozoic Periods

are for the most part of marine origin. In the Tertiaries there are also thick marine deposits, but there are also many sediments which are of estuarine or of lacustrine origin. The Tertiary formations are very difficult to classify, for they lie for the most part in isolated basins, as the London Basin, Hampshire Basin, Paris Basin, &c. These isolated beds were probably originally connected, but have been separated since the time of their deposition by denuding agents and by earth movements through whose combined action the strata originally extending from and connecting the one locality to the other, have been altogether removed and swept away.

CHAPTER XXXIV.—Quaternary System.

The Pleistocene or Glacial Formation.

General Characters of Quaternary Rocks.—The Quaternary or Fourth Great Period of geology cannot be compared with its predecessors—the Primary, Secondary, and Tertiary Ages—for the thickness of its strata; but it is of absorbing interest to us, inasmuch as for the first time Man here appears upon the scene.

This Quaternary Period embraces everything between the close of the Tertiary Period and the present day. It includes not only marine, estuarine, and fresh-water deposits, but also accumulations formed *on land* by glacial action, by wind, by organic and by chemical agents. These land deposits are preserved to us, because during the greater part of the Quaternary Period this country (and most other countries too) have remained altogether or in part above the level of the sea. We can easily understand that during the many depressions and elevations which occurred during the Primary, Secondary, and Tertiary Periods, the land now sinking down to form the bottoms of deep seas, now being elevated into mountain ranges, the sea would, as it swept over the surfaces of the sinking or rising rocks, wash away all or most of their loose

surface deposits or soils. This is, indeed, one great cause of the *imperfection of the geological record*; the existing strata are for the most part of marine or estuarine origin; of the old land-deposits but very few and scanty traces have been preserved.

The Quaternary System includes two Formations.—The Quaternary Period is divided into two formations:—

2. Recent or Post-glacial Formation.
1. Pleistocene or Glacial Formation.

The main distinction between these two quaternary formations is, that while in the lower or Pleistocene strata all the mollusca (shells) belong to living species, some of the other fossils—chiefly the mammals—have since died out or become extinct. In the higher or 'recent' strata *all* the remains found as fossils belong to species of animals or plants which still inhabit the earth.

Nature of Quaternary Deposits.—Of the Pleistocene strata by far the most important is the *boulder-clay*, which is usually a stiff and unstratified stony clay that was formed under or pushed before advancing glaciers. Beneath the boulder-clay, and sometimes interstratified with it, are sheets of *gravel and sand*, some of which may mark subsidence beneath the sea, while others are due to the melting of the ice, or to the flow of subglacial or englacial waters, or perhaps in some cases to the action of rivers at times when the cold lessened and the glaciers for a time retreated. Many beds of *peat* and of *brick-earth* were also formed during the Glacial Epoch. The Pleistocene *cave-deposits* consist of carbonate of lime (as stalagmite), and of materials (gravel, sand, clay, &c.) washed into the caves, and these cave-deposits frequently contain the bones of many animals, and occasionally the tools and weapons of the early tribes of prehistoric men who then inhabited this country.

Among the *Recent* or Post-glacial strata we must include the beds of sand and mud which fringe our rivers, and the tufa which surrounds our mineral springs. The raised beaches and submerged forests of our coast-lines belong, some to Pleistocene and some to Recent times.

Pleistocene, Post-pliocene, or Glacial Formation. (The Drift.)

Several Names for One Formation.—The strata we have now to describe in detail are called *Pleistocene* (from the Greek *pleistos*, most, and *kainos*, recent), because they are of *later* date than the Pliocene; for the same reason they are sometimes called *Post*-pliocene—the Latin prefix, *post*, meaning since or *after*. The early geologists called this formation the "Diluvium", because they thought its confused beds of clay and sand were the result of a universal deluge; but the word "Drift" (introduced by Sir Charles Lyell in 1839) is better, because it simply expresses the fact that the Pleistocene Beds have in some way 'drifted' or been pushed or removed from the original rocks of which they once formed a part. Lastly, we now call these strata *Glacial*, because modern research has shown that ice—in the form of *glaciers* and icebergs—has had much to do with their production and present positions.

The Glacial Period.—At a time whose distance from the present cannot be precisely measured in years—though Dr. Croll estimates it as *commencing* nearly a quarter of a million years ago—the climate of the British Isles (and probably of all parts of the northern hemisphere) gradually became so extremely cold, that glaciers from Scandinavia pushed southwards over what is now the bed of the North Sea, and invaded the east of England, the ice reaching as far as the northern brow of the Thames valley. The Scotch mountains themselves sent glaciers outwards in all directions, and the ice of the south-west of Scotland (Kirkcudbrightshire, &c.) joined with sheets of ice from the Lake District and pressed over the north and north-west of England, reaching southwards (when the cold was at its height) as far as the Midland Counties, for boulders of Criffel granite and of other Scotch rocks occur in abundance all round Shiffnal and Wolverhampton. At the same time the mountains of Wales and of Ireland were also deeply covered with snow and ice. Traces of the same state of things occur in all the northern parts of Europe and of Asia; and in North

America evidences of the action of land ice at this time are found as far south even as the thirty-ninth degree of latitude.

Causes of the Glacial Cold.—Many theories have been proposed to account for the intense cold which prevailed during the Glacial Period; but none can be said to be quite satisfactory, and none have as yet been generally accepted. Dr. Croll believes it to have been due to the alterations in the shape of the earth's orbit, alterations which astronomers tell us take place regularly, though very slowly and at intervals of millions of years. If so, this glacial period was only the last of many glacial periods; the traces of the earlier ones having, however, been for the most part obliterated and destroyed.

Lyell has urged that geographical changes (elevations and subsidences) would of themselves be sufficient to bring about a glacial period, which (he says) would be the result of a great continent being formed round the north pole while oceanic conditions prevailed at the equator.

Another theory is that the heat given out by the sun is not always equal, being sometimes more (when even polar countries enjoy a warm climate) and sometimes less (when only the equatorial regions are habitable). The objection to this theory is, of course, that we have no proof that our sun is a variable star.

Whatever may have been the cause of the glacial period, we know as a proved fact that a long time ago (as measured by years, although the event itself is among the latest of the many changes recorded in the geological history of the earth), the climate of the British Isles was so intensely cold that the greater part of this country was covered with ice and snow.

Origin and Nature of the Boulder-clays.—The Boulder-clay, Drift, or Diluvium was a great puzzle to the early geologists, and they solved the difficulty by taking very little notice of it. Until recently the coloured maps published by the Government Geological Survey only indicated the positions of the ordinary stratified rocks, or what is called the 'solid' geology of each district. Now, however, a second series of geological maps is being issued, on which the boulder-

clays and other superficial accumulations are carefully indicated: as these surface deposits are sometimes of great thickness it is evident that their practical interest and importance—especially in agriculture—must be very great.

The term Boulder-clay is applied to a stiff brown, bluish, or gray clay stuffed full of stones of all shapes and sizes and weighing from a few ounces to several tons, which rests indiscriminately on any or all of the stratified rocks of Ireland, Scotland, and Wales, and which in England can be traced as far south as the northern margin of the basin of the River Thames.

Several distinct beds or sheets of this boulder-clay can be distinguished. Thus in Central Scotland we have the dark tenacious clay called "Till", which is in some places as much as 100 feet in thickness. On the east coast of England at Bridlington, Cromer, &c., a similar unstratified gray clay full of angular stones occurs. At Cromer it is much contorted, the result probably of a glacier grinding into and over it.

The Great Chalky Boulder-clay extends from the Lincolnshire Wolds southwards as far as Finchley, a northern suburb of London. It receives its name from the countless lumps of chalk which it contains. It also includes many derived fossils and many stones—the latter usually smoothed, angular and striated—dragged out of or broken off the rocks over which the ice-sheet passed.

In Yorkshire the Purple Boulder-clay extends over a considerable area in the East Riding. In the centre and west of England a reddish boulder-clay covers much of Lancashire, Staffordshire, &c.

In every case the materials of the boulder-clays have been pushed southwards. Thus between Birmingham and Wolverhampton we find in it blocks of Lake District granites and syenites, and also numerous boulders of volcanic rocks from North Wales.

All this boulder-clay was probably formed in part as a 'ground moraine' beneath glaciers advancing from north to south; but much of it doubtless consists of matter contained

in or resting upon the ice, and left behind by the glaciers when they finally melted and retreated northward.

In fig. 134 we see a reproduction from a photograph of the glacial beds at Upgang, on the Yorkshire coast just north of Whitby. The beach here consists of Liassic shales covered by sand and pebbles, and above it the cliffs rise sharply to a height of nearly 100 feet. These cliffs are composed entirely of "Drift", *i.e.* of matter brought down by, in, or under ice. The upper and the lower part of the Upgang cliffs consist of boulder-clays, while an irregular bed of sand comes in between the two clays and forms the middle part of the cliffs. The lower boulder-clay is crowded with stones of all sizes up to several feet in diameter. Of these the most remarkable rock is the Shap Granite, which can be readily recognized by its large included crystals of flesh-coloured felspar. Shap lies on the east side of the Lake District, near Kendal, and the glacier which brought these boulders must have crossed the Pennine Chain and descended the Tees Valley to Middlesborough, passing thence southwards along the Yorkshire coast and mingling with the ice of the great Scandinavian Glacier which crossed the North Sea and deflected the Tees Glacier to the southward.

In fig. 135 we see a group of these Shap boulders mingled with boulders of basalt, of sandstone, and of limestone lying on the beach at Runswick, a few miles north of Whitby. The waves attack the cliffs, they wash down the materials of which the cliffs are made—sand, boulder-clay, &c.—and then they *sort out* these materials. The light particles of clay and of mud are easily carried away by the waves and the tidal currents, and they are swept southwards, to be thrown up again on the coast round the mouth of the Humber, or in the Wash, where the sea is yearly *adding to* the land. The big blocks of stone are consequently left behind, and they too are grouped together by the waves, by which in severe storms they are tossed about as if they were cricket-balls. The waves pelt the cliffs with these boulders, and by their mutual concussion they soon break to pieces, and in the course of a few years each big block

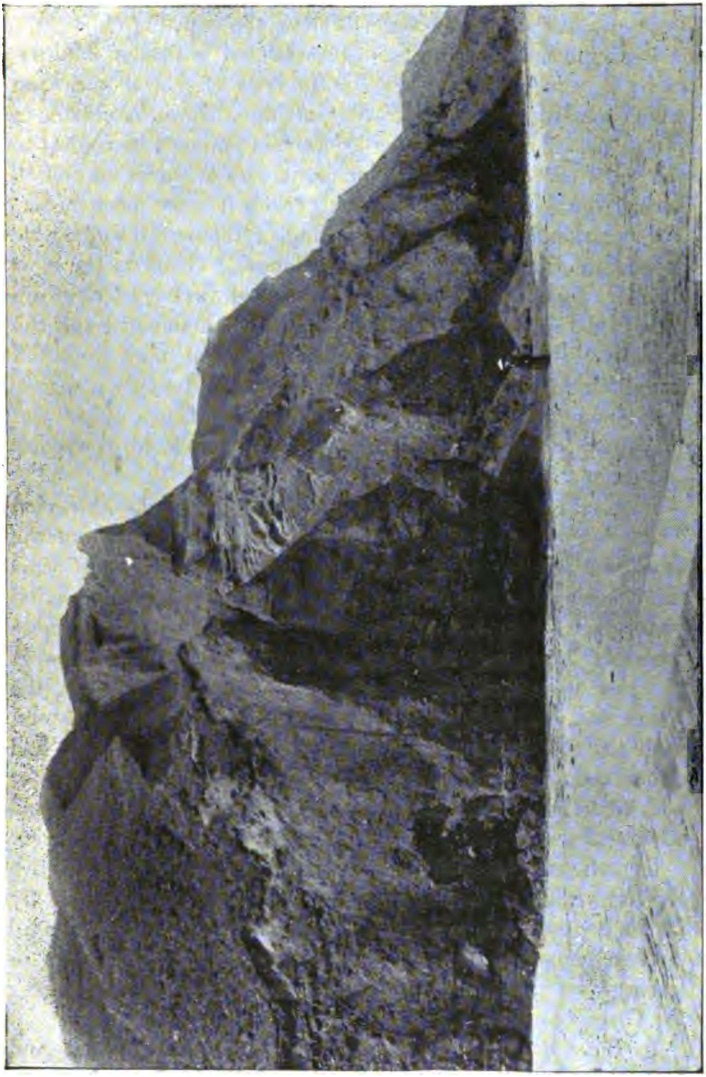


Fig. 134.—Cliffs of Boulder-clay, Upgang, near Whitby, Yorkshire.

is reduced to particles of sand and mud, while their place is taken by fresh boulders washed out of the receding cliffs.

Interglacial Deposits.—Intercalated with the Boulder-clays in some localities are certain beds of gravel and sand which sometimes contain fossil remains. These fossils are of such a nature that they have led certain eminent geologists to the belief that they indicate the occurrence of warm *interglacial* periods, but the evidence of such periods is very inconclusive. For occasionally we find a mingling of temperate and arctic species in the same 'interglacial' deposit. Thus at the New Siberia Islands, the bones of a long-haired variety of tiger are found side by side with the remains of the mammoth and the musk ox. In the Boulder-clay near Liverpool there are found two distinctly arctic shells, *Astarte borealis*, and *Saxicava rugosa*; yet along with these occur the molluscs *Venus chione* and *Dentalium tarentinum*, which are generally restricted to warmer and more southern regions.

It has been suggested that the cold of the glacial period which brought down the arctic species did not drive out the more southern forms immediately; but that for a short time there was a mingling of the two. In the case of the so-called 'interglacial' deposits of the British Isles, it would seem more probable, however, that the southern shells were simply ploughed up out of the old sea-bottoms (of the Irish Sea, the North Sea, &c.) and so became mixed, by accident as it were, with the cold-water shells which the on-coming glaciers had either brought with them from more northern regions, or which had supplanted the warm-water shells before the actual advent of the ice.

Proofs of the Former Presence of Glaciers in the British Isles.—A close study of the work *now being done* by ice in Switzerland, Greenland, and elsewhere, has convinced modern geologists that ice—in the form of either glaciers or icebergs, or possibly both—passed over these islands during the Glacial Period.

In the first place the hard rocks of Scotland, Wales, and Ireland, and of the north and centre of England, are in many

Fig. 135.—Boulders on Sea-shore, Runswick, Yorkshire.

places highly *polished* as if by the rubbing of ice. Then they are often *grooved and scratched* (striated), and the scratches or *striæ* point in just the direction from which we believe the ice came. The stones in the boulder-clay bear similar markings; and doubtless the rock-surfaces beneath were marked in this way by means of these stones, which were then frozen into the bottom of a glacier and acted like so many chisels. The hill-tops of these districts have a generally *smoothed and rounded* appearance, and the smoothed hummocks of rock (*roches moutonnées*, or sheep-backed rocks, as similar appearances are called on the Continent), all tell a tale of the passage of a heavy body of ice over their surfaces at some former period.

Boulders or "Erratics" are large angular or subangular blocks of rock which have travelled some distance from their native place. Now, if they had been *rolled* to their destinations, as by water, their corners would have been knocked off, and they would be round and not angular. We therefore think that they must have been transported by *ice*. Boulders of the granite of Shap Fell in Westmoreland (which is very easily recognized, because it contains crystals of pink felspar often one or two inches long) are found far to the south and east of the parent hill, many occurring in the boulder-clay of the east coasts of Yorkshire and Lincolnshire.

Fig. 136 represents a large boulder of felsite obtained during the excavation of one of the boating pools at Cannon Hill Park, Birmingham. The rock consists of a very fine-grained ground-mass of quartz and orthoclase felspar, with larger crystals of these minerals scattered here and there. This boulder of felsite has certainly been derived from the Arenig Mountains of North Wales (with the rocks of which area it agrees precisely in appearance and in mineralogical composition), having doubtless been transported to its present position by ice. Boulders of this rock are especially common in the Midland Counties along a tract of country extending from Wolverhampton to Bromsgrove and Birmingham, and are known by the local geologists as 'Welshmen'.

The rocky sides of the valleys in our mountainous northern

Fig. 136.—Boulder of Felsite from the Arenig Hills of N. Wales; found in Cannon Hill Park, Birmingham.

districts and in Wales are often found to be polished and scored in just the same manner as we now see the rocks to be in the valleys of Switzerland which are still occupied by glaciers. In our country the ice has gone, but many of the effects it produced still remain. In North Wales the "Pass of Llanberis" shows these traces of old glacial action very strikingly.

In the same regions of the British Isles we sometimes find great blocks of rock (perched blocks, or *blocs perchés*) poised on a bed of some other rock of a quite different nature—as granite upon slate, &c.—perhaps on the top of a hill. We believe that such perched blocks were transported by glacial ice, and then left in their present remarkable positions when the ice melted.

The Swiss glaciers leave, where they melt, a semicircular heap of stones and rubbish called a *terminal moraine*. Precisely similar moraines can be traced across the mouths of many Scotch, Welsh, Irish, and Lake District valleys.

Presence of Marine Shells at various Altitudes not an Absolute Proof of Submergence.—At the end of the Pliocene Period the British Isles were elevated until they formed a part of Western Europe, while the North Sea was a level plain, and the Straits of Dover had no existence. This elevation contributed to the cold which produced the Glacial Period. The shells which have been found in surface gravels on the top of Moel Tryfaen in North Wales (height 1300 feet), and at other elevated points in the north-west of England and in Wales, belong to species which formerly inhabited (indeed many of them still inhabit) the bed of the Irish Sea. They were *pushed up* to their present heights in front of and embedded in the ice of the "Irish Sea Glacier" which descended from the west of Scotland and (after combining with the Lake District glaciers) stretched southwards to the coasts of North Wales and the Midland Counties of England. The presence of these shells at considerable altitudes was formerly thought to prove a great depression of the land. But the shells are nearly always fragmentary, and the fragments are often striated. They did not live where they are now found.

Pre-glacial Man in Britain.—The Glacial Period or Great Ice-age did not occupy the *whole* of the Pleistocene Epoch. Before the ice came, and after it departed, the climate and conditions were such that Man and many other animals made this country their home. It is also believed by some geologists that the Glacial Period was not one of uninterrupted cold, but that there were occasional mild and brief intervals during which the glaciers retreated and the land became more or less habitable. In support of this theory they point to the beds of gravel, sand, and laminated clay which occur in or are interstratified with the boulder-clay at many places. In some localities these 'interglacial' beds contain remains of shells and of plants.

The earliest traces of man upon the face of the earth are the implements which he fashioned out of stone—usually out of flint. Now, in a cave on the eastern side of the Vale of Clwyd, in North Wales, one of these flint tools was found in 1884 *underneath* true boulder-clay. Therefore the man who made and used that tool must have lived in North Wales *before* the glacier which deposited that boulder-clay invaded the country.

At Brandon, in Suffolk, Mr. S. B. J. Skertchly (of the Geological Survey) found in 1876 a few flint implements in beds of loam which there *underlie* the Great Chalky Boulder-clay. It is easy to see why traces of pre-glacial man should be so rare; the glaciers which subsequently advanced swept most of them off the face of the country.

Summary of the Pleistocene Period.—After the close of the Pliocene Period, and while the British Isles were united on the south-east with the continent of Europe, man, accompanied by many large mammals, inhabited this country.

The whole of the west and north-west of Europe was at that time elevated considerably above its present level, the climate became intensely cold, and large glaciers pushed outwards from all the mountain ranges of Ireland, Scotland, Wales, the North of England, and Scandinavia. The moraines of these old glaciers still cover much of this country north of the valley of the Thames, and are known as 'Till', or boulder-clay.

Finally the cold diminished, the glaciers retreated, and the country once more became habitable by man, who had been driven southwards by the glacial ice, but who returned when the ice-sheet disappeared.

CHAPTER XXXV.

THE RECENT OR POST-GLACIAL FORMATION.

Strata to which the term "Recent" is Applied.—Under the name of Recent or Post-glacial we shall include all the accumulations and deposits formed since the close of the Glacial Period right down to the present day. These 'recent' beds are usually of a soft and incoherent nature, including the muds, sands, and gravels formed in rivers or lakes, or deposited as beaches and sand-banks along our coasts; the peat-mosses that fill damp hollows, the coral-reefs of tropical seas, the lavas and ash-beds ejected from active volcanoes, &c. &c. All these post-glacial rocks are being produced by the forces of nature acting at the present day exactly as they have acted throughout the enormous period of time which has elapsed since the earliest strata described in this book (the *Pre-Cambrian*) were formed.

Fossils in Recent Strata.—The shells, bones, plants, &c., which have become embedded by natural causes in the post-glacial deposits described in the last paragraph, are usually very little changed. They belong almost exclusively to species still inhabiting the earth; but, as there is no rule without its exceptions, it is found that a few animals and a few plants have died out, or become *extinct*, even in very recent times. One of the latest of these cases of the dying out or extinction of a species is that of the Great Auk (*Alca impennis*), a bird something like a penguin, which inhabited some small islands near Iceland as lately as 1830. The last survivors were killed about that time by fishermen and sailors, and the few relics of

this extinct bird which are now in existence are valued so highly that a single egg is worth £200.

The Dodo was a clumsy bird, something like a big pigeon, but almost destitute of wings. It inhabited the Island of Mauritius, and was killed off about two centuries ago by the Dutch sailors who first landed there. The *Dinornis*, of New Zealand, was an even larger bird. When erect its height was quite nine feet. The last surviving specimens are believed to have been killed by the natives (Maoris) some centuries ago.

Further back, that magnificent animal the Great Irish Elk (*Megaceros hibernicus*, fig. 137) lived in these islands along with post-glacial man, for its bones, mingled with his flint weapons, are found in several peat-bogs and caves.

Fig. 137.—*Megaceros hibernicus* (or *Cervus megaceros*), the Great Irish Elk.

But this process of the extinction of some species, and of the gradual change of others, so that we now regard them as new species, has been going on from the earliest times. Those who wish to know more about it must study the writings of Charles Darwin, whose first work in science was done in connection with geology.

Prehistoric Man.—The age in which we now live might be called the IRON AGE, because our tools and weapons are for the most part made of iron. Now, as far back as written history goes—perhaps 4000 years before the Christian era—we find constant reference to iron as a well-known metal. But the Greek author Hesiod, writing B.C. 850, does refer to a tradition current in his day of an earlier time when iron was unknown, and when *bronze* (an alloy made of copper and tin) was

used in the manufacture of implements; and unwritten history proves that this is true.

But there was an even earlier time or age—the Stone Age, when men were wholly unacquainted with the use of metals,

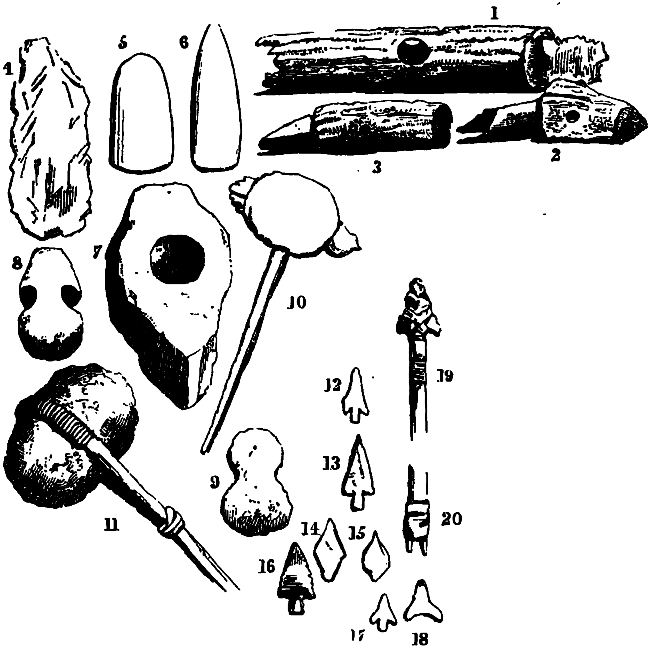


Fig. 138.—Stone Tools and Implements. 1, 2, 3, Flint flakes mounted in bone handles. 4, Palæolithic tool. 5, 6, Neolithic celts or axe-heads. 7, 8, 9, 10, 11, Stone hammers. 12 to 20, Arrow-heads made of flint.

and when their implements were made only of *stone*, bone, wood, &c. (see fig. 138).

The study of the Bronze Age belongs to the science of Archæology; but our knowledge of the Stone Age is largely due to the labours of geologists.

Two Principal Divisions of the Stone Age.—When the stone tools used by prehistoric man were carefully studied (this study only began about 1859) they were found to be of

two very distinct kinds. Those which have been found in river gravels, or in the lowest deposits of caves, have been rudely fashioned by chipping out of flint. They are usually pointed, or oval, and are from 3 to 7 inches in length. For these *older* stone tools, Sir John Lubbock proposed the name of *Palæolithic* (from Gr. *palaios,* ancient, and *lithos,* a stone). In the same deposits with these palæolithic implements were found the bones of several mammals which have since become extinct,

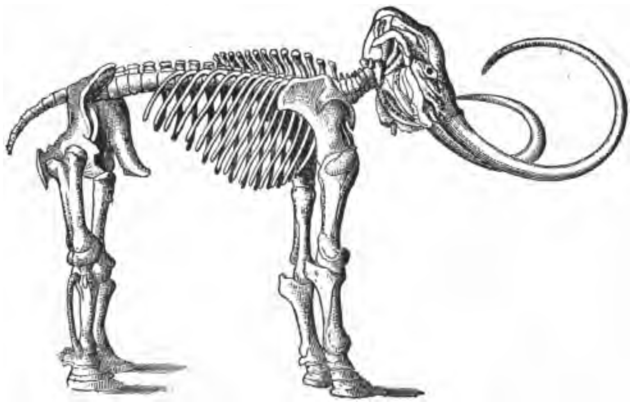


Fig. 139.—*Elephas primigenius* (the Mammoth).

as the Mammoth (*Elephas primigenius*) or woolly elephant, a huge beast covered with reddish-brown hair, and having curved tusks sometimes 11 feet in length (fig. 139); the Cave Rhinoceros (*Rhinoceros tichorhinus*), the Cave Bear (*Ursus spelæus*), the Cave Hyæna, Cave Lion, &c.

In Britain these palæolithic implements occur in the gravels of the Thames, the Ouse (at Bedford, &c.), and at many places in the south of England (see fig. 138, No. 4).

The stone tools of the second class are much more skilfully fashioned, and many of them bear marks of having been *rubbed* or *polished,* as by friction upon sandstone, &c. To these later stone tools the term *Neolithic* has been applied. They occur in the *upper* deposits in caves, and in the great mounds

of earth called *barrows* or *tumuli*, which are still seen on many of our hills, and which are the burial-places of the chiefs of these early savage tribes; and they also often turn up in the surface soil just where they happen to have been lost or thrown away. They are mostly made of flint, and some are arrow-heads, while others appear to have been used as knives, scrapers, and axe-heads (fig. 138). They are usually fashioned with great skill, and are very common on the Yorkshire Wolds, and many have also been found on the Chalk Downs of the south of England. The bones of the animals found along with these neolithic tools are all of still living species.

It is probable that the palæolithic implements belonged to tribes who inhabited this country *before* the Glacial Period. Driven southwards by the cold, their descendants returned after the glaciers had passed away; but during their long banishment these savage tribes had advanced considerably in civilization, and their tools and weapons show a corresponding advance and improvement.

Bone-caves and their Contents.—Most limestone districts contain numerous caves or hollows in the rock which have been formed by the action of running water. Such of these caverns as are accessible from the surface, appear to have been used both in historic and prehistoric times as dwelling-places by man and other animals. The floors of these caves usually consist of a reddish soil or 'cave-earth'; and very commonly there are also found on or in each floor several layers of stalagmite (see p. 48) by which the bones, &c., of the animals who inhabited the cave, or were brought into it by man, or washed into it by water, have been sealed up and preserved. In England the famous cavern called "Kent's Hole", near Torquay, has been most carefully examined by Mr. Pengelly; and similar caves are known at Brixham, Wookey Hole (in the Cheddar Cliffs), the Creswell Crags Caves (Derbyshire), the Kirkdale Cave in Yorkshire (in which the remains of over 300 hyænas were found by the late Dean Buckland), the Victoria Cave near Settle (Yorkshire), Wirksworth Cave (Derbyshire)

(fig. 140), and many more. The limestone rocks of Belgium and Germany also abound in bone-caves.

When the stalagmitic floors of these caves are broken up and examined, large quantities of the bones of various animals are commonly found, together with the stone and bone tools of prehistoric man.

Several bone-caves in the Dordogne (Central France) appear to have been inhabited by a people during the interval which

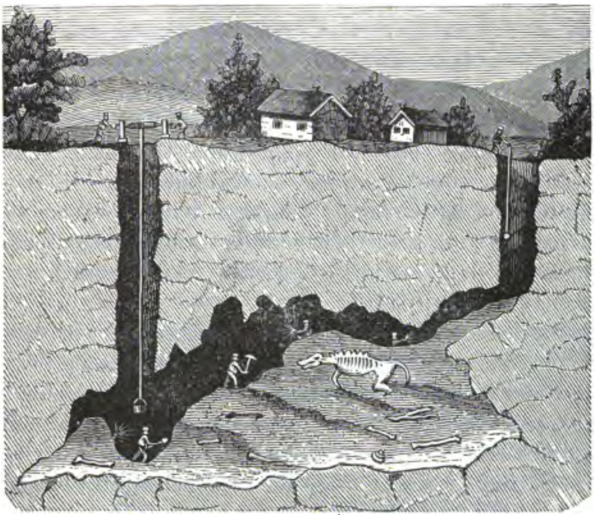


Fig. 140.—Bone Cavern at Wirksworth, in Derbyshire.

occurred in Britain between the Palæolithic and the Neolithic times. In these French caverns a piece of mammoth tusk was found on which an outline of the mammoth itself had been drawn, covered with long coarse hair just as the animal itself was during its life, so that evidently the man who drew this sketch must have seen a living mammoth. There, too, many bones of the reindeer were found. Now the climate of Central France is at present far too hot for this last-mentioned animal, which inhabits the snow-clad plains of Lapland. This fact alone tells us what a long space of time must have elapsed

since the cave-men lived in France and hunted the reindeer, for the climate of a country changes with exceeding slowness.

Alluvium, Alluvial Deposits, or Fluviatile Deposits.—These terms are applied to the gravel, sand, mud, or sediment of any kind deposited on or close to the land by the action of running fresh water. Rain and rivulets wash the soil down mountain-slopes to form plains at their feet; rivers throw up beds of sand, shingle, or mud, first on one side and then on the other of their courses, and in times of flood they deposit sediment on either side of and far beyond their original channels. In this way the Nile adds a fraction of an inch to the height of the plain of Egypt every year. When rivers enter lakes their current slackens in speed, and they drop their suspended matter near the point where they enter. In this way all such lakes are being slowly filled up. Lastly, the rivers carry their remaining sediment to the sea, and most of it is dropped at or near their mouths, forming *deltas*, and these may be called *fluvio-marine* deposits; while those formed in lakes may be called *lacustrine*.

Raised Beaches.—In South America Darwin noted in 1840 that lines of terraces occurred at heights in Bolivia of 65 feet above the present sea-level; but in Chili he found them as high as 1000 feet. They were composed of gravel, and contained numerous specimens of marine shells, such as now live in the Pacific. Each of these terraces had in turn formed the margin of the land—had been a sea-beach. These raised sea-beaches bear powerful testimony to the action of the upheaving forces which have long been in action beneath South America, and which have produced the mighty volcanic range of the Andes. In Scotland both the east and west coasts show raised beaches, one above the other, at heights of 25, 40, 50, 60, 75, and 100 feet above the present sea-level. Each of these raised beaches marks a stage when the elevation of the country was for a time arrested. Of course these old beaches are now grown over by vegetation, and are not easy to recognize at first sight; but when we dig into them we soon come across gravel, sand, and sea-shells.

River Terraces are flat narrow plains, terraces, or platforms which run along the margins of the existing rivers. Sometimes four or five such terraces can be traced, one above the other. These terraces are the remains of old alluvial plains formed by the river when it ran at a higher level. Most of them owe their formation, like the raised beaches, to an elevation of the land. When the country was raised, the slope of the rivers would be increased, and they would rapidly cut their channels lower.

Submerged or Submarine Forests.—When the land is depressed and sinks beneath the sea—as the land forming the British Isles has done many and many a time—the soil and loose surface accumulations are almost always washed away. This is the reason, no doubt, why among the stratified rocks it is so rare to find evidences of such old land surfaces. But here and there, in quiet sheltered bays, the land has been able to sink beneath a tranquil sea, and there the old surface soil has been preserved.

It is to such conditions that we owe the preservation of the 'submerged forests', traces of which are so common round our coasts. To mention a few places only, we have submerged forests at Great Crosby (mouth of river Alt, Lancashire); Poolvash Bay, Isle of Man; Porlock Bay (North Somerset); at many points on the coasts of Cornwall and Devon; Poole Harbour; Brancaster (Norfolk); Hull Docks; &c. &c. At these places at low tide, or when the sea-shore is dug away, stumps of trees are seen still rooted in their native soil, often surrounded by beds of peat, full of roots, hazel-nuts, &c., and in at least one locality (Cornwall) containing flint implements also.

Summary of the Recent or Post-glacial Formation.—The close of the Pleistocene Period was marked not only by the melting of the great ice-sheets or glaciers which had made the whole or the greater part of Britain uninhabitable, but by a slight depression of the land of Western Europe, by which Ireland was first of all separated from England, and then England from the Continent. But before this took place, many animals from the mainland had spread over our Isles. It is

interesting to notice that, while Germany has 90 native species of mammals, Great Britain has but 40, and Ireland only 22. Of reptilia and amphibia Belgium has 22, Great Britain 13, and Ireland but 4; showing that the westward migration of these animals had not been completed when the separation occurred.

But the most remarkable fact disclosed by the study of the 'Recent' strata is the appearance of Man upon the earth. Of the bones of the men who lived in prehistoric times but few traces have been found, but their stone tools are not uncommon.

In Britain we can distinguish an earlier or Palæolithic Stone Age from a later or Neolithic.

The general succession is:—

II. HISTORIC..........	From about B.C. 4000 down to the present day. Man acquainted with the working of *iron*.
I. PREHISTORIC......	(3) The *Bronze Age*: man acquainted with the working of *bronze* (an alloy of copper and tin); ignorant of the smelting, &c., of iron. (2) The *Neolithic* or *Newer Stone Age*: man still ignorant of metals, but highly skilled in manufacturing (and in polishing) stone implements. (1) The *Palæolithic* or *Older Stone Age*: man ignorant of the use of metals. Stone tools very rough; chipped out only—never rubbed or polished.

Conclusion.—The study of the earth as it exists at the present day belongs to the science of physical geography, or (as it is now often called) physiography. But it is only by this study that the geologist can understand the past history of the earth. For the forces which are at work now, modifying the face of the earth, are those which have been at work since the beginning, and which have produced the rocks whose mysteries it is the task of the geologist to discover and elucidate.

Therefore with the advent of Man upon the earth the task of the geologist is completed; but it is here that his own education should commence. We must learn first to understand the phenomena which are now occurring, and then we shall be able to explain the effects they produced in past times, effects which have been recorded in the rocks. The study of

biology—which deals with the living plants and animals of to-day, whose remains we can obtain complete and perfect—will enable us to understand the nature of the fossils in the rocks—which are usually so imperfect and fragmentary.

For just as the beginning of things—where geology merges into astronomy—is uncertain; so is the end—where our science spreads out into geography, biology, archæology, and history—certain, and constituted of facts which are still demonstrable. It is well to proceed from the known to the unknown; and therefore the study of the Earth as it is (Physiography) should precede or accompany the study of the Earth as it was (Geology).

APPENDIX I.

FURTHER HINTS ON PRACTICAL GEOLOGY.

To the student who is in earnest—who works at science because he loves it, and not with the sole object of "passing the examination"—there can be no more fascinating study than that of Geology. It has been called the "working-man's science", because—unlike chemistry, physics, &c.—it demands no expensive apparatus, and no previous training in mathematics. And then it takes one away from close rooms and evil-smelling laboratories into the open air. In such cases as that of Hugh Miller—the famous Scotch stone-mason—and of many scores of self-educated men both before and since his time, geology has shown itself able to evoke the noblest faculties of the mind; and to train intellects which would have revolted from the study of Greek or Latin, Euclid or Algebra.

Books on Geology.—Modern science has advanced with such rapid strides that no beginner should use any text-book which has not been written or revised within at least the preceding five or six years. Old books are very valuable for reference to 'old hands'; but the student who begins with them will have much to unlearn.

The present work contains the results of my experience as a teacher of the subject for more than twenty years. This—or some similar elementary text-book—should be absolutely mastered by the beginner; the alphabet of the science will then be known, and there will be obtained the power of understanding bigger and more recondite works. After this foundation of knowledge has been laid, the following books may be consulted as works of reference:—

BOOKS OF REFERENCE ON GEOLOGY.

Sir A. Geikie's *Text-book of Geology*. Macmillan, 3rd edition, 28*s*.

Professor Grenville Cole's *Aids in Practical Geology*. Griffin, 10*s*. 6*d*.

H. B. Woodward's *Geology of England and Wales*. G. Philip & Son, 2nd edition, 18*s*.

Lydekker and Nicholson's *Palæontology*, 2 vols. Blackwood, 3rd edition, 63*s*.

The Geological Magazine (Dulau & Co., monthly, 1*s*. 6*d*.).

The Quarterly Journal of the Geological Society. Longmans, 5*s*.

The Geological Survey.—This is a Government department which was established in 1835. The head-quarters are at 28 Jermyn Street, London, S.W.; and the Director-General is Sir Archibald Geikie. The officers of the Survey have walked over every field and inspected every quarry, cliff, railway-cutting, or other geological 'section' in the United Kingdom, and have mapped down and described the rocks which constitute these islands.

The principal maps issued by the Geological Survey are on the scale of one inch to a mile; and as a rule they are sold in "Quarter-sheets", each containing about 160 square miles, at a price of 3*s.* each. Upon these maps the different strata which form the surface of the ground in each locality are indicated by different colours. It will of course be a great help to the student to possess the maps which refer to his own district; and there ought to be a complete set in every local free library.

Practical Study of Rocks, Minerals, and Fossils.—It is above all things necessary that the student should *see* (and if possible handle and closely examine) the objects—the rocks, minerals, and fossils—with which the science of Geology is so largely concerned. One of the main reasons for joining a geological class or attending a course of lectures on the subject, is that the teacher usually possesses good collections which the student is allowed to examine. Every town ought to possess a good natural history museum, in whose cases the specimens illustrating the geology of the district should be especially well displayed. Probably the finest geological collections in the world are contained in the British (Natural History) Museum, South Kensington; and in the Museum of the School of Mines, Jermyn Street. No geologist should visit London without carefully inspecting both these magnificent collections.

But the student of geology will probably be ambitious of forming a collection of his own. He may do this, in the first place, by purchasing specimens from some or all of the following dealers, to whom he should write for their catalogues:—

J. R. Gregory & Co., 1 Kelso Place, Kensington, W.

F. H. Butler, 158 Brompton Road, S.W.

S. Henson, 97 Regent Street, W.

T. D. Russell, 78 Newgate Street, E.C.

For cutting rocks into thin slices suitable for examination under the microscope, we can recommend:—

Mr. T. D. Russell, 78 Newgate Street, E.C. His charge for rock sections suitable for the miscroscope is 1*s.* 6*d.* per slide.

Apparatus and advice upon blowpipe work as applied to the determination of rocks, minerals, metals, &c., will be supplied by J. T. Letcher, Truro, Cornwall.

But neither purchased specimens, nor the study of the specimens contained in museums, will do so much good to the worker in geology as the search for,

and the examination and study of the rocks, minerals, and fossils which are to be found within moderate distances of every one's home in this country. We will now proceed to give a few instructions on these points.

Field Work in Geology.—Good eyesight and a good pair of legs are of great value to the geologist. Geology must be studied in quarries, mines, railway-cuttings, sea-cliffs, gravel-pits, brick-pits; in road-cuttings and river-valleys; on crags and mountain-sides—anywhere and everywhere in the open air. Therefore, let the young geologist walk much and walk often. Keep a keen eye for every exposure of the rocks which you can find in your neighbourhood. Search for and bring home specimens of every rock, mineral, and fossil; and then try to name these specimens correctly by the help of your teachers, friends, museums, and books.

APPENDIX II.

CHARACTERISTIC BRITISH FOSSILS.

FORMATION.	NAME OF FOSSIL.	CLASSIFICATION.
PRE-CAMBRIAN, ...	——————? ...	
LOWER CAMBRIAN, ...	*Lingulella primæva*, ...	Brachiopod.
	Hyolithes, ...	Gasteropod.
	Olenellus Callavei, ...	Trilobite.
MIDDLE CAMBRIAN, ...	*Protospongia fenestrata*, ...	Sponge.
	Obolella sagittalis, ...	Brachiopod.
	Paradoxides Davidis, ...	Trilobite.
UPPER CAMBRIAN, ...	*Lingulella Davisii*, ...	Brachiopod.
	Olenus micrurus, ...	Trilobite.
	Hymenocaris vermicauda, ...	Pod-shrimp.
ORDOVICIAN—		
Arenig Series,... ...	*Didymograptus extensus*, ...	Graptolite.
	Orthoceras sericeum,... ...	Cephalopod.
	Trinucleus Gibbsii, ...	Trilobite.
Llandeilo Series, ...	*Didymograptus Murchisoni*,	Graptolite.
	Orthis striatula, ...	Brachiopod.
	Asaphus tyrannus, ...	Trilobite.
Caradoc and Bala Group, ...	*Orthis calligramma*, ...	Brachiopod.
	Strophomena grandis, ...	”
	Trinucleus concentricus, ...	Trilobite.
SILURIAN PROPER—		
Lower Llandovery Beds,	*Monograptus gregarius*, ...	Graptolite.
	Stricklandinia (*Pentamerus*) *lens*, ...	Brachiopod.
	Orthis elegantula, ...	”
Upper Llandovery, or May Hill Sandstone,	*Pentamerus oblongus*, ...	”
	Macrocheilus fusiformis, ...	Gasteropod.
	Lituites undosus, ...	Cephalopod.
Wenlock Beds, ...	*Halysites catenularius*, ...	Coral.
	Strophomena depressa, ...	Brachiopod.
	Calymene Blumenbachii, ...	Trilobite.
Ludlow Series, ...	*Pentamerus Knightii*, ...	Brachiopod.
	Cardiola interrupta,... ...	Lamellibranch.
	Orthoceras ludense, ...	Cephalopod.

Formation.	Name of Fossil.	Classification.
Old Red Sandstone, ...	*Adiantites Hibernicus,* ...	Fern.
	Anodonta Jukesii, ...	Lamellibranch.
	Eurypterus, ...	Crustacean.
	Pterygotus anglicus, ...	"
	Pterichthys Milleri, ...	Fish.
	Cephalaspis Lyelli, ...	"
	Coccosteus maximus, ...	"
	Holoptychius nobilissimus, ...	"
	Osteolepis major, ...	"
Devonian, ...	*Calceola sandalina,*	Coral.
	Spirifer disjunctus, ...	Brachiopod.
	Favosites polymorpha, ...	Coral.
	Rhynchonella cuboides, ...	Brachiopod.
	Stringocephalus Burtini, ...	"
	Cucullæa Hardingii, ...	Lamellibranch.
	Megalodon cucullatus, ...	"
	Clymenia linearis, ...	Cephalopod.
	Bronteus flabellifer, ...	Trilobite.
	Phacops latifrons, ...	"
Carboniferous—		
Lower Limestone Shales,	*Eurynotus crenatus,*	Fish.
Carboniferous Limestone, ...	*Lithostrotion basaltiforme,* ...	Coral.
	Productus giganteus, ...	Brachiopod.
	Euomphalus pentangulatus, ...	Gasteropod.
Upper Limestone Shales and Yoredale Beds,	*Goniatites sphericus,* ...	Cephalopod.
Millstone Grit, ...	*Productus semireticulatus,* ...	Brachiopod.
Coal-measures, ...	*Neuropteris gigantea,* ...	Fern.
	Sphenopteris affinis, ...	"
	Lepidodendron, ...	Lycopod.
	Sigillaria, ...	"
	Calamites cannæformis, ...	"Horse-tail".
	Anthracosia robusta, ...	Lamellibranch.
Permian, ...	*Walchia piniformis,*	Conifer.
	Productus horridus, ...	Brachiopod.
	Palæoniscus comptus, ...	Fish.
Trias—		
Bunter, ...	*Labyrinthodon* (footprints), ...	Amphibian.
Keuper, ...	*Estheria minuta,*	Crustacean.
	Lophodus Keuperianus, ...	Fish.
	Hyperodapedon Gordoni, ...	Reptile.
Rhætic Beds, ...	*Avicula contorta,*	Lamellibranch.
	Pecten valoniensis, ...	"
	Cardium rhæticum, ...	"

Formation.	Name of Fossil.	Classification.
Lias—		
Lower Lias, ...	*Lima gigantea*, ...	Lamellibranch.
	Ammonites planorbis, ...	Cephalopod.
	Ichthyosaurus communis, ...	Reptile.
Middle Lias, or Marl-stone, ...	*Rhynchonella tetrahedra*, ...	Brachiopod.
	Pecten æquivalvis, ...	Lamellibranch.
	Ammonites spinatus, ...	Cephalopod.
Upper Lias, ...	*Leda ovum*, ...	Lamellibranch.
	Ammonites serpentinus, ...	Cephalopod.
	Belemnites, ...	"
Oolites—		
Midford Sands, ...	*Rhynchonella cynocephala*, ...	Brachiopod.
	Pholadomya fidicula, ...	Lamellibranch.
	Ammonites opalinus, ...	Cephalopod.
Inferior Oolite, ...	*Terebratula fimbria*, ...	Brachiopod.
	Ammonites Parkinsoni, ...	Cephalopod.
	Clypeus Plotii, ...	Sea-urchin.
Great or Bath Oolite,	*Terebratula maxillata*, ...	Brachiopod.
	Gresslya peregrina, ...	Lamellibranch.
	Apiocrinus Parkinsoni, ...	Crinoid.
Forest Marble, ...	*Apiocrinus elegans*, ...	Crinoid.
	Hemicidaris alpina, ...	Sea-urchin.
Cornbrash, ...	*Ostrea Marshii*, ...	Lamellibranch.
	Trigonia costata, ...	"
Oxford Clay (with Kellaways Rock), ...	*Gryphæa dilatata*, ...	"
	Belemnites hastatus, ...	Cephalopod.
	Ammonites Jason, ...	"
Coral Rag, ...	*Trigonia clavellata*, ...	Lamellibranch.
	Ammonites perarmatus, ...	Cephalopod.
	Cidaris florigemma, ...	Sea-urchin.
Kimeridge Clay, ...	*Rhynchonella inconstans*, ...	Brachiopod.
	Ostrea deltoidea, ...	Lamellibranch.
	Ammonites biplex, ...	Cephalopod.
Portland Beds, ...	*Isastrea oblonga*, ...	Coral.
	Trigonia gibbosa, ...	Lamellibranch.
	Cerithium Portlandicum, ...	Gasteropod.
Purbeck Beds, ...	*Ostrea distorta*, ...	Lamellibranch.
	Cypris Purbeckensis, ...	Crustacean.
	Archæoniscus Brodiei, ...	"
Cretaceous Formation—		
Wealden Beds, ...	*Cyrena media*, ...	Lamellibranch.
	Paludina Sussexensis, ...	Gasteropod.
	Cypris Valdensis, ...	Crustacean.
Lower Greensand, ...	*Salenia punctata*, ...	Sea-urchin.
	Perna Mulleti, ...	Lamellibranch.
	Ammonites Deshayesii, ...	Cephalopod.

Formation.	Name of Fossil.	Classification.
Gault, ...	*Hamites rotundus*, ...	Cephalopod.
	Scaphites æqualis, ...	"
	Belemnites minimus, ...	"
Upper Greensand, ...	*Pecten asper*, ...	Lamellibranch.
	Ostrea columba, ...	"
	Ammonites inflatus, ...	Cephalopod.
Chloritic Marl, ...	*Terebratula biplicata*, ...	Brachiopod.
	Ammonites Rothomagensis, ...	Cephalopod.
	Nautilus lævigatus, ...	"
Chalk Marl, ...	*Lima globosa*, ...	Lamellibranch.
	Turrilites costatus, ...	Cephalopod.
	Ammonites Mantelli, ...	"
Lower White Chalk, ...	*Terebratulina gracilis*, ...	Brachiopod.
	Inoceramus labiatus, ...	Lamellibranch.
	Holaster planus, ...	Sea-urchin.
Upper White Chalk, ...	*Terebratula carnea*, ...	Brachiopod.
	Inoceramus Cuvieri, ...	Lamellibranch.
	Belemnitella mucronata, ...	Cephalopod.
Eocene Formation—		
Thanet Sands, ...	*Cyprina Morrisii*, ...	Lamellibranch.
	Pholadomya cuneata, ...	"
	Aporrhais Sowerbyi, ...	Gasteropod.
Woolwich and Reading Beds, ...	*Ostrea bellovacina*, ...	Lamellibranch.
	Cyrena cuneiformis, ...	"
	Melania inquinata, ...	Gasteropod.
Oldhaven Beds, ...	*Pectunculus terebratularis*, ...	Lamellibranch.
	Natica infundibulum, ...	Gasteropod.
	Cerithium funatus, ...	"
London Clay, ...	*Nipadites umbonatus*, ...	Palm.
	Voluta nodosa, ...	Gasteropod.
	Nautilus imperialis, ...	Cephalopod.
	Odontopteryx toliapicus, ...	Bird.
Bagshot Beds, ...	*Nummulites lævigata*, ...	Foraminifer.
	Cardita planicosta, ...	Lamellibranch.
	Voluta spinosa, ...	Gasteropod.
Oligocene Formation—		
Headon Beds, ...	*Cytherea incrassata*, ...	Lamellibranch.
	Planorbis euomphalus, ...	Gasteropod.
	Limnæa longiscata, ...	"
Osborne Beds, ...	*Cyrena obovata*, ...	Lamellibranch.
	Melania costata, ...	Gasteropod.
	Melanopsis carinata, ...	"
Bembridge Beds, ...	*Ostrea vectensis*, ...	Lamellibranch.
	Cerithium mutabile, ...	Gasteropod.
	Bulimus ellipticus, ...	"
Hempstead (or Hamstead) Beds, ...	*Corbula pisum*, ...	Lamellibranch.
	Paludina lenta, ...	Gasteropod.
	Rissoa Chastelii, ...	"

MIOCENE FORMATION.—Does not occur in Britain.

FORMATION.	NAME OF FOSSIL.	CLASSIFICATION.
PLIOCENE FORMATION—		
Lenham Sands (=Diestien of Belgium), ...	*Terebratula grandis*, ...	Brachiopod.
	Nucula sulcata, ...	Lamellibranch.
	Trochus cinerarius, ...	Gasteropod.
St. Erth Beds, ...	*Cardium papillosum*, ...	Lamellibranch.
	Turritella incrassata, ...	Gasteropod.
	Fusus corneus, ...	"
Coralline, or White Crag, ...	*Astarte Omalii*, ...	Lamellibranch.
	Voluta Lamberti, ...	Gasteropod.
	Echinus Woodwardii, ...	Sea-urchin.
Red Crag, ...	*Pecten opercularis*, ...	Lamellibranch.
	Trophon antiquum, ...	Gasteropod.
	Nassa granulata, ...	"
Norwich Crag, ...	*Astarte borealis*, ...	Lamellibranch.
	Nucula Cobboldiæ, ...	"
	Mastodon arvernensis, ...	Mammal.
Cromer Forest Bed Group, ...	*Leda myalis*, ...	Lamellibranch.
	Corbicula fluminalis, ...	"
	Cervus elaphus, ...	Red Deer.
	Elephas antiquus, ...	Mammal.
PLEISTOCENE OR GLACIAL FORMATION, ...	*Salix polaris*, ...	Arctic Willow.
	Pecten islandicus, ...	Lamellibranch.
	Astarte borealis, ...	"
RECENT OR POST-GLACIAL FORMATION, ...	The fauna and flora of historic times: including a few extinct species, such as the Great Auk, the Dodo, Steller's Sea Cow, &c.	

SCIENCE AND ART DEPARTMENT.

SYLLABUS FOR GEOLOGY: SUBJECT XII.

First Stage or Elementary Course.

The Crust of the Globe. Rocks and their Classification. Crystalline, Vitreous, and Clastic Rocks. Aqueous, Igneous (Volcanic and Plutonic). and Metamorphic Rocks.

General characters and composition of the following groups of Minerals:—Quartz, Opal, and Chalcedony; Felspars; Micas; Hornblendes and Augites; Carbonates of Lime and Magnesia; Oxides and Sulphides of Iron.

The general characters of the following types of rocks:—Granite, Diorite, Gabbro; Rhyolite, Andesite, Basalt; Volcanic glasses, Pumice, Volcanic dust; Conglomerates, Sands, and Sandstones; Clays, Shales, and Slates; Limestones and Coals; Rock-salt and Gypsum; Gneiss and Schists.

Forms of stratification. Proofs of the original horizontality of strata. False-bedding. Thinning-out and changes in the characters of beds. Ripple-mark and other features produced during deposition. Consolidation of strata; Formation of concretions; Jointing; Cleavage; Metamorphism, Elevation; Proofs of slow and violent movements in the Earth's Crust; Bending, Folding, and Inversion of Strata. Outcrop; Dip and Strike. Faults: Hade and Throw. Denudation—Subaërial and Marine. Escarpments; Outliers and Inliers. Unconformity and Overlap. Drawing simple geological sections.

Fossils: their nature and mode of preservation. Pseudo-fossils. Derived fossils. Use of fossils in distinguishing between marine and fresh-water strata. The meaning of the terms species, variety, genus, family, order. Extinct forms. Faunas and Floras.

Use of fossils in making a chronological classification of stratified rocks. Strata identified by their fossil remains. General characteristics of the forms of life in the Cainozoic, Mesozoic, Newer Palæozoic, and Older Palæozoic Eras respectively. The order of succession of the great geological systems, and the leading characteristics of their British representatives.

Volcanic rocks. Crystalline and glassy lavas. Scoriæ, lapilli, tuffs, &c. Different types of volcanic outbursts. Explosive and effusive action. Volcanic cones and their varieties. Volcanic dykes. Parasitical cones and composite volcanic mountains. Volcanic craters. Consolidation and

alteration of volcanic materials. Volcanic rocks associated with strata of different geological periods.

Plutonic Rocks. Granitic masses and their mode of occurrence; porphyritic, pegmatitic, and drusy varieties. Veins; Dykes; Sheets (sills). Included fragments and segregations. Relations of plutonic masses to the rocks into which they are intruded. Contact metamorphism around plutonic rocks. Evidences of differences of geological age in plutonic rocks.

Metamorphic rocks. Degrees of metamorphic action. Nature of minerals formed by metamorphic action. Distinctive characters of gneisses, granulites, and schists. Foliation. Mineral veins and other ore-deposits. Chief minerals occurring as ores and veinstones. Arrangement of minerals in veins. Relation of mineral veins to rocks which they traverse.

Second Stage or Advanced Course.

Distribution of temperature in the Earth's crust and the observations by which it is determined. Isogeotherms. Comparison of the density of Earth with that of its Crust. Chemical composition of the Earth's crust and of meteorites.

The common rock-forming minerals. Their forms of crystallization, physical peculiarities, chemical composition, and the characters by which they can be distinguished in thin sections under the microscope.

The macroscopic and microscopic characters of the common types of rocks. Their chemical composition, mineralogical constitution, and distinctive structures. The changes which rocks undergo as the result of surface and deep-seated action and the secondary minerals formed in them.

Distinction between False-bedding and Unconformity. Conditions of deposition as indicated by characters of strata. Origin of oolitic and other structures in aqueous rocks. Origin of flint and chert. Formation of various nodular structures. Septaria, cone-in-cone, &c. Varieties of jointing. Origin of joints. Cleavage, its nature and origin. Folds, Faults, Thrusts and their varieties.

Fault rock, slickensides, mylonites, &c. Contact and Regional metamorphism. Nature of Earthquakes and their connection with movements in the Earth's crust. Calculation of true dip from apparent dip. The methods employed in constructing geological sections and maps.

The nature of the processes to which fossils owe their preservation. Fossilization by different mineral substances. Portions of organisms that undergo fossilization. Casts, tracks, burrows, &c. The chief living and extinct groups of the Animal and Vegetable kingdoms. Range in space and time. Persistent types. Synthetic types.

Subdivision of the systems of strata into stages and zones, characterized by their faunas and floras. Limitations of the palæontological method. Homotaxy. Leading features and characteristic fossils of the series of British formations. Variations in character and thickness of the British

formations, and their general correlation with strata in Europe, North America, and other parts of the world.

Volcanic rocks of different composition and structure. Formation of peculiar types of Volcanic products. Banded, spherulitic, perlitic, and pumiceous structures. Volcanic bombs and pseudo-bombs. Pele's Hair. Ejected blocks. Chemical and physical changes which lavas undergo. Comparison of ancient and modern lavas; and explanation of the formation of secondary minerals and structures.

The chief types of Plutonic rocks. Light thrown on their mode of origin by the microscopic study of their structures and of the minerals of which they are composed. Varieties of dykes, sheets, and veins. Distinction between interbedded and intrusive igneous masses. Nature and origin of minerals produced by contact-metamorphism. Tests of age in Plutonic rocks. Veins and included fragments.

Theories of Metamorphism. Thermo-metamorphism and Dynamo-metamorphism. Varieties of foliated structure. The structure of great mountain chains and the succession of operations by which they have been produced. The origin of mineral veins and other ore-deposits. Geological age of different ore-deposits.

EXAMINATION PAPERS IN GEOLOGY.

Set at the Examinations held by the Science and Art Department.

Elementary Stage.

(The "Science Directory", price sixpence, published annually in August or September, by the Science and Art Department, contains the Syllabus and full particulars of the examinations, which are held annually in the months of May and June. It can be ordered through any bookseller.)

MAY, 1889.

You are permitted to *attempt eight* questions only.

1. How has sediment, originally soft, become converted into hard rock? (15)
2. Describe briefly any one British stratified formation, and mention its chief fossil contents. (15)
3. Arrange the following formations in chronological order, beginning with the newest: Arenig rocks, Cornbrash, Gault, Wenlock Beds, Kellaways Rock, Old Red Sandstone, Chalk. (15)
4. State the geological range in Britain of Belemnites, Rhynchonella, Ostrea, Trigonia, Nautilus, Pleurotomaria; and mention whether any of these genera are still living. (15)

5. What is gravel? Mention some important deposit of this material, stating its composition and mode of occurrence. (10)
6. Under what conditions and in what state is Gold usually found? (10)
7. Mention two living genera of animals found in Palæozoic strata, and four found in Secondary strata. (10)
8. From what rocks do we derive supplies of Common Salt, and in what ways is it obtained? (10)
9. How are landslips caused? Mention two remarkable instances of such occurrences. (10)
10. What is the general character of Boulder-clay? Give one explanation of its origin. (10)
11. How are supplies of drinking-water to be obtained otherwise than at the surface of the ground? Draw a section showing favourable conditions for obtaining a supply. (10)
12. Mention the chief districts where Granite is found in the British Islands, and give one instance where the geological age of the rock can be determined. (10)

1890.

1. Draw a section showing the following structures:—Anticlinal, Escarpment, Fault, Inlier, Outlier. (15)
2. Draw a section through any part of the British Islands, stating the geological age of the rocks shown. (15)
3. What is a Trilobite? In what rocks are these fossils most abundant? Give the names of three genera. (15)
4. Describe the action of the sea upon a cliff consisting of chalk with layers of flint. What becomes of the material worn away? (15)
5. Describe the Pliocene Beds of England. (10)
6. Roughly sketch the following fossils, and state the geological range of each:—Ammonites, Belemnites, Nautilus, Orthoceras, Scaphites. (10)
7. Note some of the characters which indicate deep-water deposits. (10)
8. What are Chalybeate springs? How may they originate? (10)
9. On what evidence should we infer that a fossil found in a certain rock has been derived from an older formation? (10)
10. How does a Volcanic Ash or Tuff differ from a Breccia? (10)
11. Describe one Limestone of the British rocks, mainly of Chemical origin, and one of Organic origin.
12. Mention the chief economic products of the Lias. (10)

1891.

1. Name two genera of fossils confined to, or especially characteristic of, Palæozoic rocks, two of Secondary rocks, and two of Tertiary rocks. (20)
2. Draw a diagram showing inversion of strata. How may inversion be proved? (20)

3. In what British formations do fossil footprints occur? (15)
4. What is meant by the *outcrop* of a stratum? (15)
5. What are ripple-marks and rain-pittings? What inferences may be drawn from their occurrence? (15)
6. Mention three British formations in which *fishes* frequently occur. (15)
7. Explain the terms Boulder-clay, Oolitic, Porphyritic, Schistose, Talus. (15)
8. Describe the chief ore of *Tin*. Where, and under what circumstances, does it occur? (15)
9. Name the British strata from which *Iron-ores* are obtained. (15)
10. What evidence have we in past geological periods, in Britain, (1) of a warmer climate, and (2) of a colder climate than at present? (15)

1892.

Only *six* questions may be attempted.

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1. Briefly describe four genera of mollusca which are confined to secondary rocks. Note their geological horizon or range. (20)
2. Define the terms *fissile, hade, joint, lode*. (20)
3. Hills frequently coincide with synclinals and valleys with anticlinals. Why is this? Draw a section to illustrate your answer. (15)
4. What are the characteristic features of the land when formed: (*a*) of a thick mass of limestone; (*b*) of clay; (*c*) of sand? (15)
5. What rocks by their decomposition produce red soils? Explain this. (15)
6. What are moraines? How do they differ from river-terraces? (15)
7. Coarse-grained sandstones are often irregular and inconstant. Why is this? (15)
8. Describe peat, and state the conditions under which it may be formed. (15)
9. What is hæmatite? Where do important deposits of this occur in Britain? (15)

1893.

Only *six* questions may be attempted.

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1. Describe the terms *Chert, Gneiss, Mica-schist, Tuff.* (20)
2. Describe *Blown Sand*. How would you recognize grains of such sand in sandstone? (20)
3. In what way may *Breccia* be formed? (15)
4. Describe how a soft calcareous deposit may be converted into crystalline limestone. (15)
5. Draw a diagram showing *Trough-fault, Inverted Strata*, and *Inlier*. (15)
6. What is *Amber*? Where does it occur, and what fossils does it often contain? (15)

7. In what British strata do the oldest known mammal, bird, and fish occur? (15)
8. What is meant by the term *hardness* as applied to water? How is this hardness produced? (15)
9. Fossil shells are often scarce in sandstones. Why is this? (15)
10. Explain the terms *bedding*, and *cleavage*. How would you distinguish these in a rock? (15)

1894.

Only *six* questions may be attempted.

---

1. Define the terms—Basin, Overlap, Thrust-plane, Unconformity. Give sketches to illustrate your answer. (20)
2. Describe and give a rough sketch of an *Ammonite*. State in what strata Ammonites are found, and to what living animals they are allied. (20)
3. How would you distinguish between *Calcite* and *Felspar*? How do these minerals originate? (15)
4. What are *Thermal Springs*? Name an English example. (15)
5. What part does *Steam* play in volcanic eruptions? (15)
6. What are *underclays*? In what strata do they occur? (15)
7. Briefly describe the main subdivisions of the *Eocene Series*. In what part of England do such strata occur? (15)
8. Mention any formations in which the following genera may be found in this country:—*Cervus, Inoceramus, Mastodon, Nummulites, Olenus.* (15)
9. What is a *Crinoid*? Mention some rocks of which such fossils are especially characteristic. (15)
10. Arrange the following formations in descending order, placing the newest at the top; and state to what great division in the geological series each belongs:—*Cornbrash, Crag, Lingula Flags, Ludlow Beds, Millstone Grit.* (15)
11. Explain under what circumstances eruptive rocks may be stratified. (15)

1895.

You are permitted to attempt *five* questions only.
The value attached to each question is the same.

---

1. Concerning a piece of chalk, state what you know on the following points:—
   (*a*) Its chemical composition.
   (*b*) The characters exhibited by it under the microscope.
   (*c*) Its mode of occurrence and geological age.
   (*d*) Its mode of formation.

2. (*a*) State the characters which distinguish basalt.
   (*b*) How can it be shown that basalt is made up of several different minerals?
   (*c*) Give the names of the minerals found in basalt.
   (*d*) How has basalt been formed?

3. Name a common English fossil belonging to each of the following groups of animals, and state in each case the stratum in which it is found:—
   (*a*) Corals.
   (*b*) Echinodermata.
   (*c*) Brachiopoda.
   (*d*) Cephalopoda.

4. (*a*) What is meant by the geological term "fault"?
   (*b*) Explain the "throw" and "hade" of a fault.
   (*c*) Draw a section to illustrate a normal fault.
   (*d*) Draw a section to illustrate a reversed fault.

5. (*a*) Explain what is meant by an "anticlinal", and draw a section to illustrate one.
   (*b*) Explain what is meant by an "outlier", and draw a section to illustrate one.

6. (*a*) How are springs formed?
   (*b*) What are mineral springs?
   (*c*) What are hot springs, and where are they usually found?
   (*d*) What are geysers?

7. (*a*) What are the "Coal Measures", and to what great system of strata do they belong?
   (*b*) Name the chief varieties of sedimentary rocks usually found in the Coal Measures.
   (*c*) State the formations *usually* found respectively above and below the Coal Measures.
   (*d*) Do the Coal Measures sometimes lie on different formations? If this is the case how do you account for the fact?

8. If you were shown the following fossils:—
   (*a*) *Gryphæa incurva*;
   (*b*) The tooth of an elephant;
   (*c*) Calamite-stem;

   what would you state as to the group of plants or animals to which they respectively belong, and the beds from which they must have been originally derived?

   (*d*) If you were told that all three fossils were found together in the same pit, how would you account for the fact?

1896.

You are permitted to attempt *five* questions only.

The value attached to each question is shown by the number in brackets at the end of each.

---

1. State the chemical composition, the crystalline system, and the specific gravity of the following common rock-forming minerals:—
   (*a*) Quartz.
   (*b*) Orthoclase felspar.
   (*c*) Augite.
   (*d*) Magnetite. (20)
2. State what you know on the following points:—
   (*a*) The chemical composition of Rhyolites.
   (*b*) The minerals which occur in Rhyolites.
   (*c*) The difference between Rhyolites and Granites.
   (*d*) The difference between Rhyolites and Andesites. (20)
3. Give diagrams with descriptions of the following:—
   (*a*) Overfolded strata.
   (*b*) Unconformity.
   (*c*) An escarpment.
   (*d*) A reversed fault. (20)
4. State the group of plants or animals to which the following fossils belong, and the strata in which they are found:—
   (*a*) Calamites.
   (*b*) Belemnites.
   (*c*) Trilobites.
   (*d*) Graptolites. (20)
5. (*a*) To which of the great geological eras do the Jurassic, Triassic, and Cretaceous systems belong? Place them in their proper sequence.
   (*b*) Give the name of a Jurassic echinoderm, a Triassic echinoderm, and a Cretaceous echinoderm.
   (*c*) Give the name of a Jurassic cephalopod, a Triassic cephalopod, and a Cretaceous cephalopod.
   (*d*) Give the name of a Jurassic vertebrate animal, a Triassic vertebrate animal, and a Cretaceous vertebrate animal. (20)
6. (*a*) Of what different kinds of materials are volcanic cones built up?
   (*b*) Draw a section showing the internal structure of a scoria or "cinder" cone.
   (*c*) How is the crater of such a cone formed?
   (*d*) What is meant by a parasitical cone? (20)
7. (*a*) In what respects do veins and dykes differ from one another?
   (*b*) What kind of rocks are found forming veins and dykes respectively?
   (*c*) What effects are produced by dykes on the rocks through which they pass?

(*d*) What effects are produced when dykes and the enclosing rocks are subjected to denudation? (20)

8. (*a*) How does gneiss differ from granite?
(*b*) How does a slate differ from a shale?
(*c*) Name three minerals commonly found in rocks altered by contact metamorphism.
(*d*) Name the chief varieties of schist. (20)

Second or Advanced Stage.

MAY, 1895.

You are permitted to attempt *five* questions only. The value attached to each question is the same.

---

21. (*a*) Name the minerals usually found in granite, giving the chemical composition of each of these minerals, and describe:—(*b*) Porphyritic granite. (*c*) Graphic granite. (*d*) Drusy granite.
22. In what respects do the rocks, in each of the following pairs, respectively resemble one another and differ from one another? (*a*) Granite and Gneiss. (*b*) Shale and Clay-slate. (*c*) Oolite and Statuary Marble. (*d*) Common Coal and Anthracite.
23. Draw sections illustrating:—(*a*) False-bedding. (*b*) Unconformity. (*c*) How would you distinguish between False-bedding and Unconformity? (*d*) Explain what is meant by "overlap".
24. Explain the differences between interbedded and intrusive volcanic rocks, and describe the tests you would apply in order to distinguish one class from the other.
25. State the grounds for the belief that the cleavage of rocks has been produced by pressure.
26. Explain, with the aid of diagrams, the following phenomena, exhibited by stratified masses:—(*a*) Contortion. (*b*) Inversion. (*c*) Overfolding. (*d*) Overthrust.
27. State what you know concerning the chief divisions of the British Cambrian strata, and the fossils which they contain.
28. What are the chief argillaceous formations in the British Jurassic series, and by what fossils may each be distinguished? Name the other strata which separate these great clay formations.

MAY, 1896.

You are permitted to attempt *five* questions only. The value attached to each question is shown in brackets after the question.

---

21. (*a*) State the nature of the observations by which the earth's density has been determined. (*b*) What are the results obtained by these

observations? (c) State the densities of the heaviest and of the lightest rocks forming the earth's crust. (d) What is the probable average density of the materials composing the crust of the globe? (40)

22. How would you distinguish between the following minerals as seen in thin sections under the microscope? (a) Orthoclase felspar and plagioclase felspar. (b) Augite and Enstatite. (c) Magnetite and Pyrite. (d) Quartz and Opal. (40)

23. State the mineralogical constitution and the general characters of the following rock-types:—(a) Augite-andesite. (b) Hypersthene gabbro or Norite. (c) Spherulitic Pitchstone. (d) Pyroxene-granulite ("trap-granulite"). (40)

24. How do you suppose the following kinds of rock to have been formed? (a) Oolitic limestone. (b) Flint. (c) Clay-slate. (d) Mylonites. (40)

25. State the grounds on which the following conclusions are based:—(a) The Wealden formation was deposited in fresh water. (b) The Wealden formation is younger than most of the Jurassic strata. (c) The Wealden formation is older than the "Lower Greensand". (d) While the Wealden formation was being deposited in the South of England, marine strata were being formed in (a) the North of England (b) the Alpine region. (40)

26. What were the chief volcanic rocks erupted in the British Islands in—(a) Pre-Cambrian times? (b) The Older Palæozoic Era? (c) The Newer Palæozoic Era? (d) The Cainozoic Era? (40)

27. (a) In what respects do Plutonic rocks resemble volcanic rocks? (b) In what respects do Plutonic rocks differ from volcanic rocks? (c) State the grounds on which we are able to form a theory as to the origin of Plutonic rocks? (d) Why are Plutonic rocks belonging to the younger geological periods so extremely rare? (40)

28. Describe the following rocks and their mode of occurrence--(a) "Augen-gneiss". (b) Chiastolite slate. (c) Saccharoid limestone. (d) Quartz-schist.

For Answers to all the Elementary Questions set in this subject since 1883, see *Guide to the Examinations in Geology*; by W. Jerome Harrison, F.G.S.; published by Blackie & Son, price 6d.

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Names of persons are printed in small capitals, and names of fossils in italics.

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